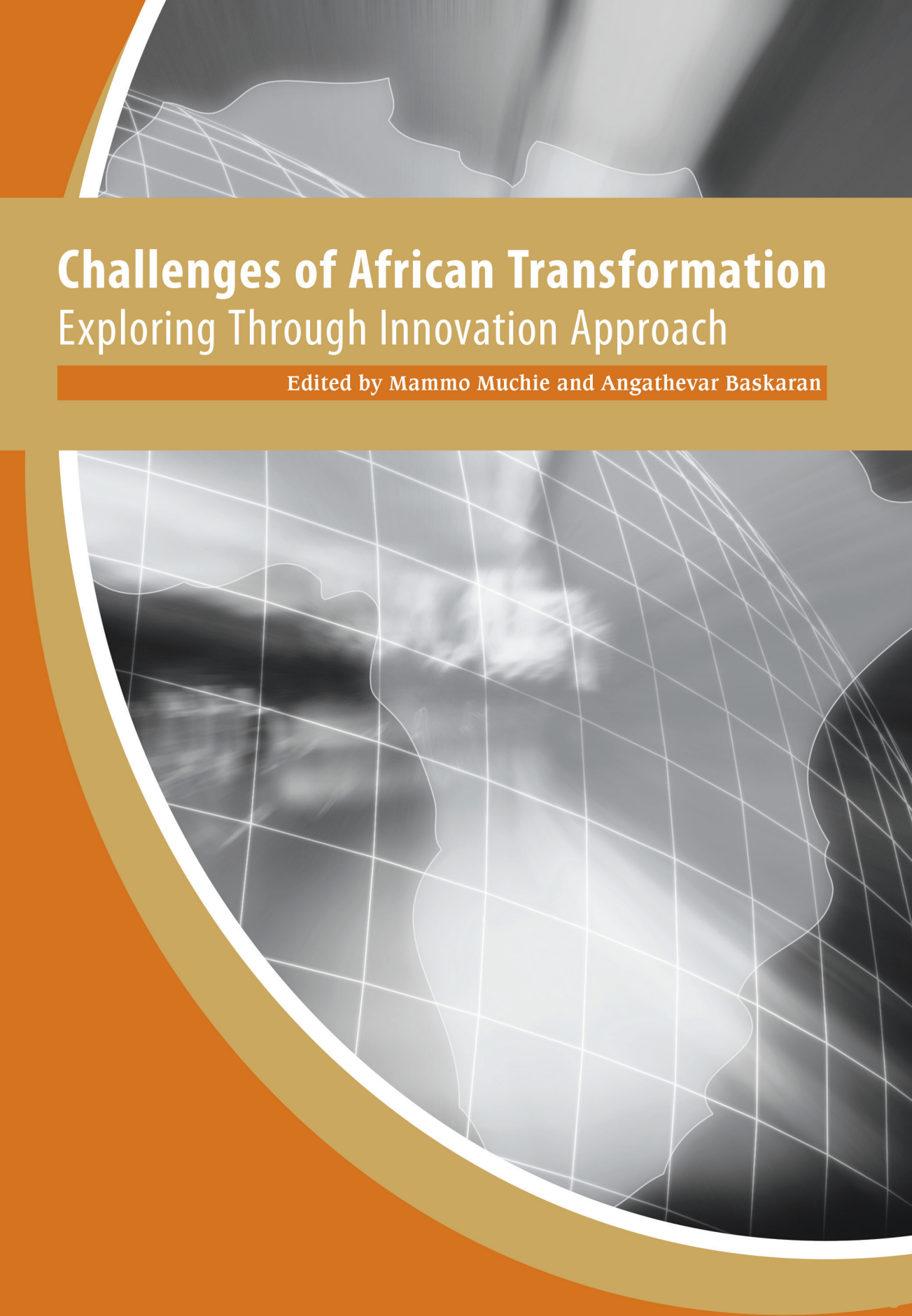




Challenges of African Transformation

Exploring Through Innovation Approach

Edited by Mammo Muchie and Angathevar Baskaran

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DEDICATION

Mikael and Adey Muchie and all the children of
Africa to stand up and innovate a strong, free,
confident, independent and proud Africa.

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Preface

The South African Research Initiative (SARChI) started the research applying the innovation systems theory approach to African problems of development and structural transformation since 2008. Throughout the last four years the SARChI chair has concentrated research on innovation to address the challenges of African development. This is inspired by the vision that Africa's bright future is better created by making it rather than predicting a destination to reach at some unknown date.

The SARChI started the African Journal of Science, Technology, Innovation and Development in 2008 and have published four issues every year. It is the expectation that six issues will be published in 2013 with Taylor and Francis publishers. This has been an important outlet for emergent African researchers as nearly 70 per cent of those who publish in the journal are Africans, both in Africa and abroad. The objective is to create a publishing outlet in Africa with ISI listing. This will enable researchers to produce and publish research papers that are peer reviewed with high impact factors. The African Journal of Science, Technology, Innovation and Development are firmly on track in achieving the recognition and rating that will make it sustainable. It is one of the key milestones of the DST/NRF Research chair in innovation and development that Tshwane University was offered. The journal has a web site: www.ajstid.com

This book series is another milestone which SARChI chair initiated. This volume has earned the distinction in 2012 of being the first to start the production of a series of books on the systematic application of the innovation system approach to the challenges and opportunities of accelerating and fully realising the creation of an African national innovation system. The application of systems of innovation framing and theories to African problems of development is still new. The field has been dominated by development studies. This book series offers an alternative by proposing systems of innovation approach to generate knowledge, learning and competence-building in Africa.

It is with utmost responsibility we open this alternative innovation approach by warning our readers that the selection is not to transfer and apply without any alteration to embed in African economic and social change, but to find new ways of creating knowledge that will make a difference by prioritising the African reality and discovering convincing ways to understand and explain them. The innovation approach can serve two purposes; explore and demonstrate critically how the development question in Africa has been addressed hitherto. Critique is necessary, but not sufficient. What

the volumes do is create, by using appreciative and grounded theorising, an empirically rich exploration of the African reality in order to understand and change it.

No knowledge is final. There are different ways of creating knowledge. The epistemic superiority of any new approach has to be demonstrated. The key challenge is to position the innovation approach in the African context to create new insights that inspire policy learning in order to change the African development matrix.

– *Mammo Muchie and Angathevar Baskaran*

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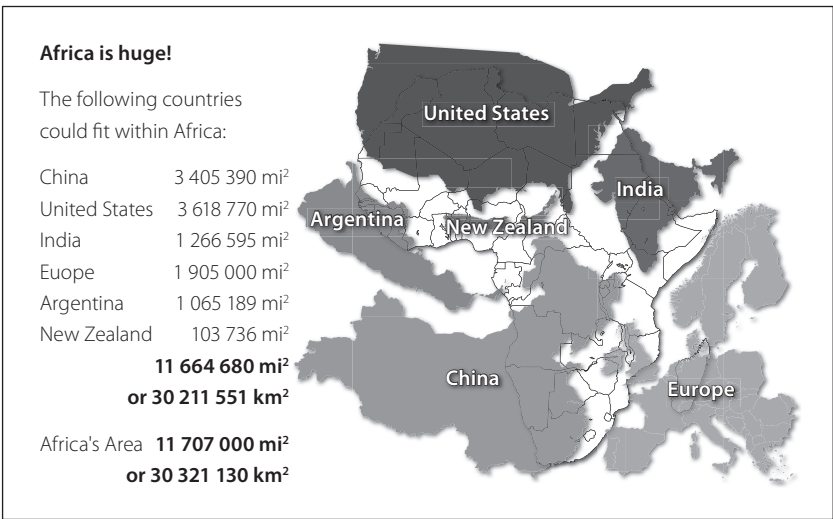
Watu Wamae: Development, Policy and Practice, The Open University, Walton Hall, Milton Keynes,

Introduction

Mammo Muchie

A brief overview of the African economic picture reveals a paradox where the continent that has rich mineral resources, nearly a billion people and a land mass which includes the sizes of China, USA, India, Western Europe, Argentina together and still is larger than the sum of these regions is in an unacceptable state of being an object of aid, debt and loans despite the vast resources both known and yet to be explored in it for the whole post-colonial period (See Map below). Africa should have been a production and innovation centre and not a charity and aid centre of the world where 'donorship' has replaced African national ownership' of not just Africa's resources, but even worse, Africa's own agency, autonomy and independence to shape policy and direction; to undertake African integrated national development by establishing a science, engineering and technology based knowledge, innovative, learning and competent economy. The main thrust of the African quest to unite both the politics and the economy flows from a recognition that Africa must organise a production, economic and innovation system by integrating producers with producers, producers with users, users with users in Africa and for Africa. This is both desirable and possible and knowledge of how to do it 'know-how-know-what, know-why and know-whom', must be assiduously cultivated. The continent must emerge fully as a region free from the donorship gaze it suffers from unjustly at the

Map 1 Map Showing the Real Size of Africa



moment by often threatening to cancel its national agency and independence. Building a strong African system of innovation will go a long way to change the existing fragmented circumstance with a unification logic that will change the existing conditions and realise fully the wellbeing of the people.

It is clear that the actual size of Africa is far larger than the Africa seen on most maps.

It is no exaggeration to state that African political and economic arrangements today are characterised by internal pervasive and schizophrenic disconnections, mismatches, fragmentations and external dependence. Nearly 70 per cent of Africa's overall population exist in subsistence and primary resource and agrarian conditions. Where a country has the overwhelming portion of its production as agricultural, that country invariably remains vulnerable even to feeding itself, conversely where a few percentage of a nation's population is working on the land and is engaged in manufacture and services for the most part, that country is more likely to feed itself whether it rains or not.

In Africa, most countries today share the following broad characteristics:

1. The linkage among the agriculture, manufacture and services within each country remains weak
2. The linkage between the vast informal and relatively smaller formal economy remains weak
3. The integration of science, engineering and technology in the economy in transforming agriculture into manufacture and producing high value added radical products remains weak
4. The traditional export of primary commodities and importing manufactured products at a rate that is often unequal remains to this day

It appears to be a serious economic strategy that integrates in every country, agriculture with manufacture and both with services, and all to be driven by science, engineering and technology remains yet to be forged.

In many ways the fact such linkages are weak can paradoxically open the opportunities to build an integrated African national economy where these linkages can be forged on a Pan-African scale, scope and foundation.

The interesting problem is how much African countries that suffer from an economic arrangement that continues to short-change all Africans realise that the current pattern of triple integrations, namely; internally, between agriculture, manufacture, services; externally, between African economies and the rest of the world are largely unsustainable, forming a Pan-African engagement with one another not only is desirable but also necessary.

Only when African economies are able to integrate agriculture with manufacture by applying science, engineering and technology that they will be able to change the current unequal relations they are in today with the rest of the world economy.

As Frederick List put it:

"The elevation of an agricultural people to the condition of countries at once agricultural, manufacturing and commercial, can only be accompanied under the law of free trade, when the various nations engaged at the time of manufacturing industry shall be in the same degree of progress and civilization; when they shall place no obstacle in the way of the economical development of each other, and not impede their respective progress by war or adverse commercial legislation."¹

The main pattern of Africa's economic relations with the world economy is what will make Africa permanently vulnerable, unless it changes its conditions through continuing unequal primary agriculture and mineral exports for the products manufactured elsewhere. African countries produce similar primary products for the same market and compete against each other thus accentuating their fragmentation.

Africa faces a true dilemma: if it is able to insulate itself from the world economy, it can incur possible welfare, income and knowledge losses. If it integrates on current dominant patterns of relating on the basis of primary commodity transactions with the world economy, it faces continued economic dependence and fragmentation and lack of structural transformation of its fundamental economic structure.

Africa's current pattern of inclusion in the world economy comes at the cost of fragmenting the African economic and political space. It appears the continued cost of fragmentation is supposed to be offset by Africa being in the international aid system. Whether African fragmentation can be offset by dependence on aid or national development should be a genuine issue for investigation and reflection.

The problem is that after half a century of post-colonial independence, African economies continue to be fragmented in spite of the AU/NEPAD salutary processes. The more the fragmentation among African economies deepens, the harder for each of the fragments not to be supplicants to the aid system. Africa thus also faces another critical dilemma of being addicted as a long-term victim of the burgeoning aid industry that has created a business of what is known as 'technical assistance' where those who provide the aid consume most of the resources allocated, and the recipient Africans continue to be in a vulnerable position as long-term aid receivers without a way to get out of this dependency situation. 'Charity corrupts, long-term charity corrupts long-term.'² In general, it may not be easy to

disprove aid is not useful to some within the recipient countries. This does not validate, however, aid or the aid system per se, since it is not difficult to show that the long-term impact of aid is negative, if we proceed from the normative preference that the recipient countries options to plan their development free from conditions imposed that often do not take the specific context of the countries, can be misdirected by aid system.

It is thus no exaggeration that a country relying on aid is most likely not to develop a national strategy without the interference and the factorings of the interests and policies of the aid system. Being a recipient in an international system for many African countries has not brought development but corruption and poverty. It undermines the country from making mistakes and learning from the routines and practices of the possible economic evolutionary activities. Africa cannot afford to continue to suffer the opportunity cost from continuing to receive aid, only to defer building the much needed ability to create the capacity, capability, competence, learning and innovation to transform the largely agrarian and subsistence economic system.

The key problem is the challenge of building the national system of innovation in fragmented states that appear to be caught in a prisoners dilemma fifty years after most of them attained independence from the European powers that previously controlled them. What is not clear is how much opportunity there is of building sustainable systems of innovation on the basis of the current AU, NEPAD and the regional economic communities. If the choice is to continue, based on the current fragmented logic, the chance of building a system of innovation capability that will make a difference may not be obtained. It is possible a few countries in Africa may progress within the current state arrangements (e.g South Africa, Nigeria etc.). It is not clear when and how they can do this by playing unfair rules. It may even open Africa to a system of innovation paralyses, where many states get caught in an unstable state of a non self-regenerating national system of innovation. The question is: can the regional economic communities neutralise the fragmentation of the states or do they create region-level fragmentation by not fully overcoming the current state level fragmentations? What will be the unit for building a sustainable and transformative system of innovation? African Unity First may be able to provide a dynamic African national system of innovation building to address the complex challenges of forging an integrated Africa open to the knowledge and learning economy. There is a need in Africa to define a new research agenda to provide metaphors, heuristics, alternatives and the resources for an emancipatory research and practice in the rebuilding of an African integrated national system of economy and production driven by knowledge, learning, innovation, and competence building systems (AfricaKlics) through the applications, skills and products of science, engineering and technology.

‘There is no Pan-African and integrated conception of how learning, competence building, science and technology may be integrated with production and users. In practice, a common Pan-African perspective on how to build innovation and competence building systems needs yet to be forged.’³

The chapters in this volume address the application of the innovation approach to a variety of problems in Africa. The chapter by Frank K Teng-Zeng on the historical development and challenges of science and technology indicators in Africa reviews the work done to date on innovation indicators. In recent years, there has been growing national and international attention to the availability of science, technology and innovation (STI) indicators. Increasing demand for evidence-based policy making instruments means that STI indicators have become part and parcel of the national and regional development planning processes including competitiveness measures in many economies. This research focuses on STI indicators development in Africa. It reviews the importance of and how collection of STI data and publications has evolved in many developed and emerging economies, including regional cooperation and integration institutions, but less so in Africa. It highlights certain challenges in producing and disseminating STI indicators, but acknowledges some national and regional efforts towards that as well as the NEPAD African Science, Technology and Innovation Indicators Initiative programme to produce an African STI Indicators Outlook. The Author recommends that any sustained growth of STI indicators in the continent requires the building of appropriate STI studies research centres and networks.

The chapter by Abdelkader Djeflat on Building Systems for Innovation ‘Take off’ in African Economies problematises the catch up phenomenon. The author argues catch-up assumes that innovation takes place in a linear model with path dependant trajectory characterising the innovation process. What he characterises as ‘innovation take-off’ rests on the premise that innovation systems need strong policy impulses from government stimulate innovation. Innovation take-off is the prerequisite for innovation systems to operate in a conventional manner. In many developing countries, innovation systems construction takes place in a very specific environment characterised by the rise of a small and medium scale enterprises (SMEs) sector but with little experience in the fields of R&D, relatively weak industrial performances in terms of productivity, and high level of obsolescence both in terms of human resources and equipment. The author argues that while the approach in terms of innovation systems is real and attracts a great deal of attention from policy makers, very little work has been done on the way African countries could engage in a real take-off policy of their innovation system in a sustainable manner. The research contributes to highlight and address the fundamental question of how innovation takes

off in late industrialising countries such as African countries, both in terms of policies and conceptual framework. He draws lessons from the Algerian experience and takes further the conceptual and theoretical approach that have been developed in earlier works on industrial technical centres as a way to trigger off innovation.

The chapter by Bengt-Åke Lundvall: *Innovation in Africa - Toward a Realistic Vision*, explores innovation and development in the African context. The author argues that after less than forty years Rosenstein Rodan's (1943) seminal article that started the era of 'classical development economics', there is a need for a fresh approach. Hirschman (1981) gave an address where he recognised that the era for development economics had come to a close. Hirschman pointed out that he and his colleagues had overestimated the power of their ideas to overcome underdevelopment and he specifically referred to a lack of respect for the emotions and culture of those who were expected to realise the ideas. I believe that Hirschman was right, not least concerning the African experience, and this is one reason why this writer sees the establishment of a strong research capacity on innovation and economic development within Africa as fundamental for the formation of strategies that can bring Africa out of underdevelopment.

The chapter by Laxmi Prasad Pant and Helen Hambly-Odame on the innovation systems approach to renewable natural resource management and sustainable agriculture has been recognised as a new conceptual tool. However, there is a lack of systematic review of literature in this emerging field of inquiry. This review of over 100 relevant contributions concludes that there have been two major paradigm shifts in agricultural science, technology, innovation and development – from the transfer of technology approach to the various research and extension systems, and then to innovation systems. Innovation systems in agriculture have two major theoretical foundations – innovation systems in manufacturing, and various systems approaches in agriculture. The review revealed that it is imperative to establish a new generation of innovation systems research in renewable natural resources that integrates three apparently distinct fields of studies – environmental management, international development and innovation studies.

The chapter by Jo Lorentzen is a review of the literature on innovation in the world's poorest (or low-income) countries (LICs), published between 1997 and 2008. It asks what role innovation plays in the LICs, and how much and what exactly we know about it. It shows that traditional innovation studies, in particular, has rather neglected the LICs. Most research addresses problems concerning agriculture and health and focuses not on firms but on individuals, households, and communities as principal units of analysis. The author's research showed that the literature is rather

fragmented and there is no evidence of a systematic research agenda concerning innovation of and for the Bottom Billion. He suggests that there are a few incipient themes – such as learning, community participation in development projects (a concept close to user-driven innovation), or innovation diffusion versus technology transfer – around which a LICs-focused research programme could emerge.

The article by Loesse Jacques Esso explores the interaction between capital markets' imperfections and the agents' occupations in a technologically non-advanced country. He built a two-period overlapping-generations growth model with heterogeneous agent, by supposing that agents inherit ability and a technique of production from their parents. He showed that when information in the capital markets is imperfect the occupational choices of agents are endogenous. He also found that there are two endogenous thresholds of ability which allow distinguishing lenders, R&D innovators and implementers who produce intermediate goods with lagged productivity. His findings revealed that the growth rate and convergence depend both on the level and the structure of human capital. Capital markets influence economic growth and convergence through technology.

The chapter by Bitrina Diyamett argues that under the current competitive environment the word 'innovation' has become catchy. Much of the academic discourse and policy targets are on how to spur innovative activities among national firms. Although the debate on factors facilitating innovative activities is far from being settled, it has concretely been established that innovation is systemic and context specific and therefore its facilitation requires multidimensional and context specific approaches. The author proposes that innovation in the African context can best be built through cluster initiatives.

It further argues that while the cluster concept is practical, the concept of systems of innovation is basically an ex-post rather than ex-ante concept, and therefore cannot easily be applied in building systems of innovation, especially in the African context. The Tanzanian Cluster Initiatives Project that is showing positive results is used to back the theoretical arguments.

Watu Wamae argues that actual technological spillovers are not substantial in developing countries because of the weak absorptive capacities. A panel data analysis is used in an attempt to gain insight into the specific aspects that enable economies to benefit from the backlog of existing knowledge. The findings indicate that low productivity effects of human capital coupled with weak or virtually non-existent systems of innovation, are at the root of the observed ambiguity with regard to the spillover gains that are expected to play a significant role in sparking growth.

The chapter by Rebecca Hanlin and Judith Sutz builds on the idea that embedding social policies within innovation policies and vice versa is one

of the main ways to place the power of academic research at the service of those at the bottom of the pyramid. The authors analyse systematically the problems that prevent research from fulfilling the promise of modernity and progress for vast majorities of the world population, and attempt to propose ways to overcome such problems.

Vusi Molo proposes that an African village of Matamong possesses a design theory of *letanta*, an artifact used to catch small animals like *nogwaja*. *Letanta* is designed within the confines of a set of irreducible invariants and the requirement to venerate the spirits. The premise of this design philosophy is to reduce and possibly eliminate the prohibitive cost of survival through an iterative process of infinitesimal changes which eliminate extraneous material so that the final artifact engenders a survival maximizing experience.

The author suggests that analytical and interpretive findings show that an indigenous artifact like *letanta* provides an empirical evidence of the superiority of simple design concepts which deliver compact solutions to the great question of survival adaptation.

CONCLUDING REMARK

Together the chapters highlight the critical importance of the innovation systems approach in each of the issues the authors preferred to select and analyse. In the African context, the application of innovation goes beyond firms to the informal activities at grassroots level. The boundaries and the range of actors and activities for innovation application are varied and not limited. This variation is represented in this volume by the diverse issues that the authors dealt with in their research by applying as common the use and application of innovation.

Future research in Africa needs to address social innovation systems that focus on how the social needs and wellbeing of ordinary people can be addressed. Research should focus on how systems of innovation for smart economic growth can be developed. In addition new areas must be explored and researched such as the question on systems of innovation for inclusive growth; for justice fairness and equitable distribution of resources to enhance the welfare of people starting from the least advantaged, for poverty eradication and for sustainable development and for removing spatial, region and geographical disparities and uneven development. Can systems of innovation that overcome irrational fragmentations and help construct a project identity be built? How about systems of innovation that can combine modern scientific knowledge with indigenous local knowledge? How about systems of innovation capability for knowledge exchange rather than

for knowledge transfer from those with strong systems of innovation to those with very weak systems of innovation? What would work better: promoting system of innovation based on broad based innovation or system of innovation with high tech content or combining them to create new synergies and syntheses? These new areas require further and in-depth research. These are all waiting to be done. This volume points in the right direction to start this research systematically, to create a body of knowledge that will enrich the learning culture gleaned from grounded scrutiny of the various problems and challenges, in order to bring about structural change in Africa by cultivating the enduring culture of knowledge, learning, innovation and competence building in Africa.

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- 2 David Elleman: *Helping People Help themselves: from the World Bank to an Alternative philosophy of Development*; Michigan University Press, Anarbor, 2006, p. 12.
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Science and Technology Indicators in Africa

Historical Development and Challenges

Frank K Teng-Zeng

SUMMARY

In recent years, there has been growing national and international attention to the availability of science, technology and innovation (STI) indicators. Increasing demand for evidence-based policy making instruments means that STI indicators have become part and parcel of the national and regional development planning processes, including competitiveness measures in many economies. This research focuses on STI indicators development in Africa. It looks at the importance of how collection of STI data and publications has evolved in many developed and emerging economies, including regional cooperation and integration institutions, but less so in Africa. It also highlights some of the challenges in producing and disseminating STI indicators, but acknowledges some national and regional efforts towards that as well as the present NEPAD African Science, Technology and Innovation Indicators Initiative programme to produce an African STI Indicators Outlook. Any sustained growth of STI indicators in the continent requires the building of appropriate STI studies research centres and networks.

INTRODUCTION

The availability of science, technology and innovation statistics and indicators in a country or region is becoming increasingly important in measuring and analysing socio-economic development, transformation, cooperation and competitiveness. The long history in gathering these data and growth in Science and Technology Studies as a sub-field of scientific enquiry attest to this development in developed countries, and now in emerging economies. However, the importance of science, technology and innovation (STI) indicators cannot be limited to developed and emerging economies

because the usefulness of the statistical information and their systematic analysis in poor countries to promote socio-economic development, cannot be overemphasised (Tijssen and Hollanders, 2006; Gault, 2008).

The main focus is on STI indicators development in Africa, the importance of STI indicators and how the collection of data and subsequent publications has evolved in many countries and among regional cooperation and integration institutions. Section Two gives a brief general overview of STI indicators development and importance in advanced and emerging economies. Section Three identifies and gives a historical overview of science and technology indicators in Africa. It discusses the individual national efforts and institutions responsible for generating and managing STI statistics in selected African countries. It also covers international efforts aimed at producing indicators in African countries and the current continental efforts under the African Union (AU) and the New Partnership for Africa's Development Programme (NEPAD) African Science, Technology and Innovation Indicators (ASTII) Initiative. Further, this section highlights some individual scholarly and institutional works on science and technology indicators in Africa. Section Four looks at STI policy studies, research centres and networks in Africa, some of whose activities cover indicators. Finally, more reliable and systemic data collection and analyses are needed on Africa. However, this is only possible if there is a critical mass of dedicated STI studies and research community working in cooperation with relevant national agencies, such as statistical departments. This requires national governments and external support as a short-to-medium strategy to develop the appropriate infrastructure and technical expertise in a sustainable way.

A BRIEF GENERAL OVERVIEW

Historically, by the time most African countries gained political independence in the late 1960s, data collection on science and technology (S&T) indicators in a country had assumed great importance, especially among member countries of the Organisation for Economic Cooperation and Development (OECD) with the publication of the first methodological manual, popularly referred to as the *Frascati Manual* (for Research and Development surveys). This was later followed by the publications of the *Oslo Manual* (for innovation surveys) and the *Canberra Manual* (for human resources surveys), to name a few here (see Arundel et al., 2006).¹

However, in a recent essay, Godin (2003:680) argues that the publication of *Science Indicators (SI)* by the United States of America (USA) National Science Foundation in 1973 marked the clear beginning of the development

of indicator systems. This is because the *SI* publication was 'widely acclaimed, discussed worldwide and served as a model for several countries and organisations'. He posits that following the *SI* publication, the OECD started a series entitled *Science and Technology Indicators* in 1984. Various OECD member countries established/supported some national institutions to produce periodic S&T indicators. Also, some individual governments in developing countries, mostly in Asia and Latin America, started producing time-series data. Thus, the growth and development of STI indicators can be viewed more positively on the basis of the following functions, among others, that indicators can serve in the socio-economic development of a country or region including, but not limited, to: decision making/policy making; research and analysis and informing the general public. Thus, evidence-based policy requirement has fuelled the growth of STI indicators data collection and analysis (see Gault, 2008; Lepori et al, 2008).²

With increasing interest in regional cooperation and integration, the survey and publication of regional science, technology and innovation indicators also gained much currency in the early 1990s, especially within the European Community and later in Latin America and South East Asia (see next section). The European Commission published the First European Report on Science and Technology Indicators in 1993. The European Commission in partnership with Eurostat also began the Community Innovation Surveys (CISs) series in European countries. Meanwhile as part of the move towards the European Research Area (ERA), the European Network of Excellence on Policies for Research and Innovation in Europe (PRIME) was created under which the European Network of Indicator Producers project (ENIP) was launched.³ Table 1 provides a list of selected countries and organisations and publications.

Furthermore, like the various interests in the national systems of innovation approach, sectoral indicators are increasingly gaining significance with biotechnology, information and communications technologies and nanotechnology as some of the key areas where the OECD countries are leading the process. The OECD published *A Framework for Biotechnology Statistics* in 2005 and revised a version of it in early 2009. There has also been growing international interest in Regional Science and Technology Indicators in the developed and emerging economies.

Another important issue to consider in the STI indicators development is that the ever-growing interest in this field of research and innovation activity has resulted in different kinds of indicator generating community and the relevant clientele. For instance, Lepori and his colleagues (2008:35) observe that the multiplication and differentiation of the demand for indicators has led to a considerable broadening of the field regarding 'the *level of analysis*, the *type of indicators*, the *consumers* and *their uses*'. This

translates into at least three different categories of indicator producers and users namely: (i) A new governance structure which implies a multiplication of the levels of aggregation; (ii) Differentiation of the needs and the uses of indicators; and (iii) Multiplication and diversification of the customers.

The above categorisation is of significance to the African STI indicators Initiative, the policy-making and scholarly community on the African continent.

STI INDICATORS IN EMERGING ECONOMIES

Although the availability of national S&T indicators or sectoral indicators in most advanced economies may be taken for granted, in most developing countries the story is different. However, there has been gradual capacity building and production of science and technology indicators in some developing countries, especially the emerging or newly industrialising economies. For example, the Indian Government's Department of Science and Technology (DST) was set up in 1971. Over the years, the department has acted as the nodal agency to foresee the establishment of a S&T statistical system and collects national science statistics at regular intervals in the country.

As part of these efforts, the National Science and Technology Management Information System Division (NSTMIS), a division of DST, is entrusted with the responsibility of carrying out studies relating to resources devoted to S&T activities at regular intervals. The Division published the first report on Research and Development Statistics in 1973–74 (NSTMIS, 2007).⁴ Today the NSTMIS produces the National Research and Development Statistics at A Glance report biennially as well as the National Innovation Survey Report (NSTMIS, 2008).

In Singapore, the National Survey of R&D was conducted by the Singapore Science Council on a triennial basis between 1978 and 1987. Since 1990, the Agency for Science, Technology and Research (A*STAR), has been conducting regular surveys and publishes the *National Survey of R&D in Singapore* annually (A*STAR, 2008).

The Malaysian Science and Technology Information Centre (MASTIC) conducts regular surveys to produce the Reports on National R&D Surveys and the Malaysian Science and Technology Indicators since 1992 biennially (MASTIC, 2006). China's Ministry of Science and Technology is responsible for national surveys and produces the Chinese Science and Technology Statistics Data Book every year. The Republic of South Korea's Ministry of Science and Technology oversaw the conducting of regular national R&D surveys for many years before the country became a member of the OECD. Meanwhile, the Association of South East Asian Nations (ASEAN) took

Table 1 List of Science and Technology Indicators Publications
in Selected Developed Countries

No.	Country/ Inst.	Lead Agency	Title of Publication	Year	Frequency
1	United States	National Science Foundation (NSF)	Science and Engineering Indicators (from Science Indicators)	1973	Biennially
2	Germany	Federal Ministry for Education and Technology	Federal Research Report	1965	Every 4 years
			Technological Competitiveness Report	1985	Annually
3	France	Observatoire des Sciences et de Technologie (OST)	Science & Technologie-Indicateurs	1990	
4	Japan	National Institute of Science and Technology Policy (NISTEP)	Science and Technology Indicators	1991	Every 3 years
5	Multilateral	Organisation for Economic Cooperation and Development (OECD)	Main Science and Technology Indicators	1984	
6	Regional	European Commission	European Report on science and Technology Indicators	1993	
7	Multilateral	UNESCO	World Science Report	1993	

Source Author's own compilation

key interest in the member states generating S&T data which led to the publication of the First ASEAN Science and Technology Indicators in 1997 with the support of UNESCO and United Nations Development Programme (ASEAN, 1997). This was followed by the publication of the ASEAN Science and Technology Competitiveness Indicators in 2004.

In Latin America, STI indicators surveys and publications of data has been both a national and regional priority. The Brazilian Ministry of Science and Technology (MCT) has been responsible for the publication of the country's Science and Technology Indicators with regular national R&D surveys. Argentina and Chile, together with other members of the Ibero-American and Inter-American Network on Science and Technology Indicators (Red Iberoamericana de Indicadores de Ciencia y Tecnologia – RICYT), which includes Spain and Portugal as members),⁵ produce regular STI indicators. Information available shows that STI data has been updated to cover the

Table 2 Selected National Science, Technology and Innovation
Indicators Agencies/Institution in Developing Countries

Country	Centre/Institute	Abbreviation	Year	Website
Malaysia	Malaysia Science and Technology Information Centre	MASTIC	1992	http://www.mastic.gov.my
Singapore	Agency for Science, Technology and Research	A*STAR		http://www.a-star.edu.sg/astar/home.do
India	National Science & Technology Management Information System, Department of Science and Technology	NSTMIS		http://www.nstmis-dst.org
China	Ministry of Science and Technology	MOST		http://www.most.gov.cn/eng/index.htm
Korea Republic	Ministry of Education, Science and Technology	MEST		http://english.mest.go.kr
Thailand	National Science and Technology Development Agency	NSTDA	1991	http://www.nstda.or.th/en/
Thailand	National Innovation Agency	NIA	2003	http://www.nia.or.th
Thailand	Thailand Institute of Scientific and Technological Research	TISTR	1979	http://www.tistr.or.th
Brazil	Ministry of Science and Technology	MCT		http://www.mct.gov.br
Regional	Ibero-American and Inter-American Network on Science and Technology Indicators	RICYT	1995	http://www.cicyt.ac.ar
Regional	ASEAN Science and Technology Network	ASTNET	1995	http://www.astnet.org

Source Compiled by the Author

period from 1990 to 2007 including classifications on ‘information per country, comparative indicators on financial resources, human resources, publications and patents’ (RICYT, 2009). In 2001, RICYT co-published the Bogotá Manual on measuring innovation developing countries. There is the Ibero-American Observatory of Science, Technology and Society (OCTS-OEI) in Latin America. At present, RICYT is working on a project ‘Towards an

Inter-American System of Science, Technology and Innovation Indicators, Basic Platform', with funding from the Organisation of American States (RICYT, 2009). Growing interest in the knowledge and information society led to the publication of the *'Lisbon Manual, Guidelines for Interpretation of Available Statistical data and Construction of Indicators for Ibero-American Transition to the Information Society'* in 2006, and a revised version of the manual in 2009. Table 2 shows some of the STI indicators generation and publication institutions in selected developing countries.

HISTORY OF SCIENCE AND TECHNOLOGY INDICATORS IN AFRICA

While the efforts outlined have facilitated and promoted science and technology development by influencing government support for research and development through the analysis of the input and output indicators of the science and technology systems over the years; and supported the building of a vibrant science and technology studies community in these countries and regions, not much has happened in the case of Africa. Therefore, it is essential to examine the status quo.

INDIVIDUAL NATIONAL EFFORTS

In Africa, the only major efforts on STI indicators development come from South Africa and a few selected countries in North Africa. Thus, as the most scientifically advanced and Africa's largest economy, South Africa is by far the country with the most relevant S&T information and experience in generating S&T statistics. Boshoff and Mouton (2003) and also Blankley and Kahn (2005), in a recent review of science and technology measurements in South Africa, indicate that the country initiated its first OECD Frascati-based R&D Survey in 1966. The survey was carried out on a biennial basis first by the South African Council for Scientific and Industrial Research and later in partnership with the Human Sciences and Research Council between 1977/78 and 1991/92. The survey process was put on tender and awarded to the Foundation for Research and Development (FRD).⁶ The FRD then published two editions of *SA Science and Technology Indicators* in 1993 and 1996, but no survey was carried out during the 1995/96 cycle. However, the National Research and Technology Audit made available R&D survey data for the 1997/98 period. This was again followed by a gap until the 2001/02 R&D Survey results were published in 2004 (DST, 2004). Prior to that, the National Advisory Council on Innovation (NACI) published a small booklet with the latest available figures for selected S&T indicators in the country with some data dating back to 1997/98 (NACI, 2002).

In 2002 the Centre for Science and Technology and Innovation Indicators (CeSTII), Knowledge Management Group of the Human Sciences Research Council (HSRC) was created and commissioned by the Department of Arts, Culture, Science and Technology shortly before its split into the Department of Science and Technology (DST) and Department of Arts and Culture to conduct the 2001/2002 R&D survey (DST, 2004; Blankley and Kahn 2005). To make the R&D survey results official statistics, the DST and Statistics South Africa signed a memorandum of agreement to that effect in 2005. After the 2003/04 R&D Survey, CeSTII now conducts annual R&D surveys (Kahn, 2008).

Meanwhile, with innovation surveys increasingly being undertaken in the OECD countries, South Africa also conducted the country's first innovation surveys in 1996 and the second on a limited scope based on the OECD Oslo Manual in 2001 (UNU-INTECH, 2004). However, these two surveys are considered unofficial and the response rates were less than 10 per cent. The DST commissioned the CeSTII to conduct the country's first official South African Innovation Survey in 2005. It covered the 2002-2004 period on a much broader scope and achieved a higher response rate of 37.3 per cent (Blankley and Moses 2009; Kahn 2008).

Complementing the efforts of these R&D and innovation surveys is work at the Centre for Research on Science and Technology (CREST) at Stellenbosch University. This university has been developing a research capacity in bibliometric analysis and has a database known as *SA Knowledgebase* containing scientific articles produced by South African scholars and researchers dating back to 1990.

Elsewhere in the continent, the Government of Mozambique published a national science and technology indicators report in 2003, while Tunisia published a similar report in 2004, Ethiopia in 2005, and Egypt in 2008. By 2005, South Africa was the only country in Africa to have conducted major innovations surveys. However, Arvanitis (2007) reports that Tunisia and Morocco have undertaken some innovation surveys at the level of firms. Also, Mhenni (2008) reports of innovation surveys for Tunisia covering the period 2002-2004. Meanwhile, Tunisia has established the National Observatory of Science and Technology.

Recently, sectoral indicators especially for the higher education sector are now available in some countries. Tanzania published its higher education statistics in 2005; Uganda in 2004; while Ghana's National Council on Tertiary Education produces higher education enrolment and staff data. The ongoing review of the Nigerian national research and innovation system may also produce possibly the best coverage of the country. The lack of STI indicators on Nigeria has always been a surprise because a good number of the continent's STI scholars and researchers come from that country.

INTERNATIONAL AND CONTINENTAL EFFORTS

Although there have been limited national efforts in generating national STI statistics in Africa, international organisations, including the United Nations Education, Social and Cultural Organisation (UNESCO) have over the years attempted to collect and collate data from various countries, but their efforts have been hampered by the low number of countries that respond to their questionnaires. African countries' poor response to the recent surveys carried out by the Montreal-based UNESCO Institute for Statistics (UIS) is a good example, although Ellis (2008) argues that the response rate has improved from 35 per cent in 2004 to 57 per cent in 2006. The World Bank's World Development Indicators is also relevant, but there are some gaps in the coverage for African countries' S&T. This is not unexpected because, in most cases, the World Bank also relies on UNESCO for R&D data. However, a sectoral approach in agricultural science and technology indicators under the auspices of the International Food Policy Research Institute (IFPRI) seems to currently provide a better coverage for most African countries.

Given the importance of STI indicators within the African continent, the United Nations Economic Council for Africa (UNECA) commissioned a study undertaken by the former FRD. It produced a report in 1995. The purpose of this study was to provide 'a guide for compiling science and technology indicators in a country, that can help the decision makers to understand the relationship between S&T indicators and socio-economic development, and thus provide adequate support to this area so as to enable it to accelerate overall socio-economic growth' (UNECA, 1995).

Almost a decade after the UNECA report, however, the African Union's New Partnership for Africa's Development programme (NEPAD) First Ministerial Conference on Science and Technology for Development which was held in Johannesburg, (South Africa) in November 2003, reiterated Africa's commitment to developing science and technology, and to providing innovation indicators at national and regional levels to help in policy formulation in order to address the socio-economic development needs of the continent (NEPAD, 2003). Following the NEPAD S&T Ministerial Conference, the NEPAD Secretariat commissioned the United Nations University/Institute for New Technologies (UNU-INTECH) in Maastricht, the Netherlands, to design a policy-relevant innovation survey for Africa in 2004. The NEPAD Secretariat was considering the idea of introducing an innovation survey to cover 17 African countries (UNU-INTECH, 2004). As part of the Africa's Science and Technology Consolidated Plan of Action (CPA) adopted in 2005, NEPAD Office of Science and Technology has initiated the African Science, Technology and Innovation Indicators Initiative programme (ASTII) (NEPAD-OST, 2005).

CHALLENGES

The developments over the years cited in the preceding section indicate how difficult it is to generate, collate and disseminate relevant information on STI activities in Africa in time-series manner. One question to ask is: how come many African countries do not have such relevant information to assist in policy formulation and national development planning processes. Several possible answers can be offered.

First, there have not been any concerted national efforts to have such relevant information as part of national development planning in most countries. This is evident from the fact that most important science and innovation studies or surveys conducted in many African countries were the result of external donor interests (both bilateral and multilateral). For instance, in the recent UNU-INTECH (2004) study undertaken for NEPAD, most of the surveys identified were supported by international development agencies such as the World Bank, United Nations Industrial development Organisation (UNIDO) and UNESCO, among others, under various programmes.

Secondly, national institutional and research capacity in this field has not been well developed. For example, with over 300 universities and institutes of higher learning and research in Africa, only a handful work in the field of science, technology and innovation studies (see section 4 below) and financial support of national governments to such centres is limited. In most instances, early science and technology policy studies institutes were created in the public sector outside of the higher education sector and there were weak linkages between them for purposes of human resource capacity building and joint research.

Thirdly, national statistical institutions, which are pioneers in STI indicators data generation and management bodies in developed countries, have weak capacities in most African countries in terms of both human resource capacity and information and telecommunications infrastructure to support their activities. Besides, most of the individual national statistical agencies lack the necessary experiences in STI surveys or data generation and management on the continent.

Another serious challenge is perhaps the internal mobility of skilled personnel who were engaged in some STI indicators development and research capacity building process, but who often move to other agencies in different fields of research interest.

To address some of these challenges, NEPAD has expressed the ‘ need for capacity building which can be addressed by the African Observatory for Science, Technology and Innovation (AOSTI) through the provision of training, sample survey instruments, and study templates, as

Table 3 Selected Institutions involved in S&T Indicators in Africa

No.	Country	Institution	Sector
Research Institution			
1	South Africa	CeSTIL- HSRC	Public Sector
2		CREST	High Education
3		ITI	High Education
4		IERI	High Education
5	Senegal	Centre National de Documentation Scientifique et Technique (CNDST)	Public Sector
6	Ghana	Science and Technology Policy Research Institute	Public Sector
7	Nigeria	National Centre for Technology Management (NACETEM)	Public Sector
8	Tanzania	Tanzania Commission for Science and Technology (COSTECH)	Public Sector
9	Ethiopia	Ethiopian Science and Technology Agency	Public Sector
Government Ministry			
10	Algeria	Centre de Recherche en Economie Appliquee pour le Développement	Higher Education
11	Angola	Ministry of Science and Technology	Ministry
12	Burkina Faso	Ministry in Charge of Science and Technology	Ministry
13	Egypt	Ministry of Scientific Research	Ministry
14	Gabon	Ministère de l'Enseignement Supérieur	Ministry
15	Kenya	Ministry of Science and Technology	Ministry
16	Lesotho	Department of Science and Technology	Ministry
17	Malawi	Department of Science and Technology	Ministry
18	Mali	Ministère de Recherche Scientifique et Technologique	Ministry
19	Mozambique	Ministry of Science and Technology	Ministry
20	Senegal	Ministry of Scientific Research	Ministry
21	South Africa	Department of Science and Technology	Ministry
22	Tanzania	Ministry of Science, Technology and Higher Education	Ministry
22	Tunisia	Ministry of Science and Technology	Ministry
23	Uganda	Ministry of Tourism, Trade and Industry	Ministry
24	Zambia	Ministry of Science, Technology and Vocational Training	Ministry
Statistical Agency			
25	Cameroon	Institut National de la Statistique du Cameroun	Public Sector
26	Ethiopia	Central Statistical Agency	Public Sector
27	Gabon	Direction General de la Statistique et des Etudes Economique	Public Sector
28	Ghana	Ghana Statistical Services	Public Sector
29	Kenya	Kenya National Bureau of Statistics	Public Sector
30	Malawi	National Statistics Office	Public Sector
31	Mali	Direction Nationale de la Statistique et de l'Informatique	Public Sector
32	Senegal	Agence Nationale de la Statistique et de la Démographie	Public Sector
33	Uganda	Uganda Bureau of Statistics	Public Sector
34	Zambia	Central Statistical Office	Public Sector

Source Compiled by the Author; NEPAD-OST, 2008.

well as a practical advice on the development of country profiles, indicators reports and the use of indicators in evidence-based policy' (NEPAD-OST, 2005). Since 2007, NEPAD's ASTII project has been instituted with initial funding support from the Swedish International Development Agency (SIDA) and participating African member states.

Following the ASTII Intergovernmental Committee Meeting in Maputo, Mozambique, in September 2007 (NEPAD-OST, 2007; Gault, 2008), the First ASTII Training Workshop for African Countries was held in Centurion, South Africa, in March 2008 (NEPAD-OST, 2008). A Second ASTII Workshop on Harmonization of Science, Technology, and Innovation Indicators in Africa was held in Johannesburg, South Africa, in March 2009. Currently, there are 19 African countries participating in the National R&D and Innovation Surveys under the auspices of AU/NEPAD in partnership with the Research Policy Institute of Lund University in Sweden. These countries include: Algeria, Angola, Burkina Faso, Cameroon, Egypt, Ethiopia, Gabon, Ghana, Kenya, Lesotho, Malawi, Mali, Mozambique, Nigeria, Senegal, South Africa, Tanzania, Uganda and Zambia. Publication of the first African Innovation Outlook (AIO) is planned for in 2010.

The African STI indicators programme further received a boost when, in February 2009, the African Union (AU) Assembly of Heads of States and Governments accepted a proposal put forward by the Government of Republic of Equatorial Guinea to make available an initial funding of US\$3.6 million and space towards establishing the AOSTI as part of implementing the CPA. The AU Assembly also invited Member States, Regional Economic Communities (RECs), UNESCO, the European Union, nongovernmental organisations and other partners to support the initiative and make it sustainable (AUC, 2009). Although the Government of Republic of Equatorial Guinea should be commended for its offer of support, the country should have taken part in the on-going ASTII surveys, since very little is known about its STI system.

Notwithstanding these difficulties, some individual scholars and institutions have produced research reports and articles which sometimes focus on Africa, but often contain selected information on certain countries. Much of this has been produced by scholars, think-tank groups and institutions outside the continent or in collaboration with local partners largely because of near absence of an S&T indicator scholarly and research community in the different African countries, with a few exceptions (see for example, Adeboye, 1998; Blankley & Kahn, 2005; Boshoff and Mouton, 2003; Davis, 1983; Ellis, 2008; Gault, 2008; Gaillard et al., 2005; Kahn 2008; Pouris 2003; Tijssen 2006; UNESCO, 1986). Thus, STI Policy Studies remain critical if the present efforts of growing the human resource and institutional capacities are to be realised.

With regard to institutions involved on STI indicators research, Table 3 above indicates that South African institutions conduct more research in this sub-field. The South African National Advisory Council on Innovation (NACI) has established the Indicators Reference Group to support the growth of this sub-field and enable it to offer appropriate policy advice to enhance the growth and competitiveness of the national economy.

SCIENCE, TECHNOLOGY AND INNOVATION POLICY STUDIES IN AFRICA⁷

The future of science, technology and innovation indicators development will be influenced by the general growth of STI Studies in the continent, which remains a challenge. For example, Muchie, Gammeltoft and Lundvall (2003) in their recent work – *Putting Africa First: The Making of African Innovation System* – argue that “The African system of political economy is waiting to be written” (Muchie et al, 2003:9). This is in contrast to the industrialised countries where much work has been done on national innovation systems and still continuous with rigorous interrogation of the concept at the macro-, meso- and micro-levels by scholars and researchers in Science, Technology and Innovation Policy Studies. In fact, Africa is the only region where scholarly interest in innovation systems analysis is beginning to take off (Lundvall et al, 2002:216).

The statement that ‘The African system of political economy is waiting to be written’ and the fact that NIS analysis is about to take off after almost two decades of resurgence in scholarly work on research and innovations systems raises interesting questions on the extent of work done on STI policy and research in the African continent. Nevertheless, scholars mostly based outside the continent who sometimes work in collaboration with their counterparts in Africa have undertaken several research and innovation systems policy studies in the past few years. Recent initiatives include the programmes supported by the European Commission as part of the EU’s Framework Programme for Research and Technological Development aimed at opening up the ERA to the rest of the world through cooperation. Examples of these studies, which are relevant to African Research and Innovation Systems, are the Evaluation of Scientific and Technological Capabilities in Mediterranean countries (ESTIME) project coordinated by Rigas Arvanitis at the Institut de Recherche pour le Developpement (IRD) in France. The project covered eight countries in North Africa and the Middle East, including Morocco, Tunisia, Algeria and Egypt. It was funded by the European Commission from September 2004 to February 2007. ESTIME projects aimed at providing indications on the level of research, technological development, and innovation in these countries (Arvanitis, 2007).

As part of its sponsored collaborative programme between the three engineering faculties/colleges at the University of Dar es Salaam in Tanzania, Eduardo Mondlane University in Mozambique and Makerere University in Uganda, the Swedish International Development Agency (SIDA/SAREC) supported the first Regional Conference on Innovations and Innovative Clusters in Africa, which was held in Bagamoyo, Tanzania, from 18–20 February 2004. The primary objectives of the conference were ‘to develop awareness among African participants about the concept of innovations and innovation clusters...afford the participants the opportunity to brain-storm on what could be adopted and adapted to speed up industrial and economic growth in Africa’ (Mwamila et al., 2004:vii).

The second Regional Conference on Innovations and Innovative Clusters in Africa was organised in 2005 where a proposal was put forward towards the development of ‘Innovation Systems and Innovative Clusters Programme’ for East Africa (Turyagyenda and Lugujjo, 2005). In June 2004, the African Technology Policy Studies Network also launched a Working Group on National Systems of Innovation and was in the process of developing a full concept paper. The Nairobi-based African Centre for Technology Studies (ACTS) launched the ACTS Institute of Science and Technology Policy Analysis and Training in 2005. International partners include Harvard University, Pennsylvania State University in the United States of America (USA) and Strathclyde University in United Kingdom (UK). All these are laudable efforts. However, some questions may still be raised on the research activities and interests of certain academic and research institutes and centres in Africa in the past two decades, given the dearth of literature on research and innovation system (RIS). S&T indicators are virtually non-existent in some of the ‘key’ countries/economies in the continent.

Interests in RIS in developing countries received a further boost when the United Nations announced in early 2005 that it plans to establish a major institute dedicated to technology studies in poor countries. This initiative brought together two existing research centres based in Maastricht, The Netherlands, – the Maastricht Economic Research Institute on Innovation (MERIT) and the United Nations University Institute for New Technology (UNU-INTECH) to form the new institute, UNU-MERIT in 2006. UNU-INTECH was already involved in the Innovations and Innovative Clusters research in Africa and the merged institution still has a focus on Africa. In fact, as part of the efforts UNU-MERIT was a key partner that helped in organising the Eighth Global Network for Economics of Learning, Innovation, and Competence Building Systems (GLOBELICS) International Conference held in Dakar, Senegal, in October 2009.

In 1993, one of the key issues raised in the International Development Research Centre (IDRC) report on the South African science system was that the capacity to undertake studies in STI was lacking and should be developed. This report influenced the establishment of research units such as the Science and Technology Policy Research Centre (STRC) at the University of Cape Town in July 1995. The early IDRC support for STRC covered the full remuneration costs of two researchers for a period of three years, while the Centre for Science Development (CSD) awarded STRC its first four-year cycle grant (Kaplan 1999:20). STRC activities, however, collapsed. The Institute for Technological Innovation, University of Pretoria, was established in 1994; the Centre Research on Science and Technology (formerly Centre for Interdisciplinary Research), University of Stellenbosch, was established in 1995; while the Institute for Economic Research and Innovation (IERI), at Tshwane University of Technology (TUT), was officially launched in September 2004. IERI helped in hosting the GLOBELICS 2005 Conference in Africa from 31 October – 4 November 2005 in Pretoria, South Africa. As part of the South African Research Chairs Initiative (SARCHI) launched in 2006, TUT was granted the first Chair in Innovation Studies in 2007. This position has been taken up by Professor Mammo Muchie who is a professor at the Research Centre on Development and International Relations at Aalborg University in Denmark.⁸

In addition, the Centre for Science, Technology and Innovation Indicators (CeSTII) was created within the Human Sciences Research Council (HSRC) Knowledge Management Group by the South African Department of Science and Technology in 2002. CeSTII has been conducting regular annual national R&D surveys for the country since 2003.

The difference in the current wave of STI studies in South Africa is that the major research units are located within the higher education sector or Science Councils with good links between them. This is markedly different from the situation in Sub-Saharan Africa where STI studies centres are created outside the higher education system (except for the Technology Planning and Development Unit and later National Centre for Technology Management (NACETEM) both at the Obafemi Awolowu University Ili-Ife in Nigeria and the Institute for Development Studies at University of Dar-es-Salaam in Tanzania). In 1994, the Africa Technology Policy Studies Network (ATPS) was created following the merger of the Eastern, Southern and West African Sub-regional Networks. The early linkages between STI studies centres outside universities and those in universities within the continent were very weak. Although some individual academic staff may have links with the centres outside the university systems, these centres have failed to grow a critical mass of researchers in STI across the continent. The under-

developed nature of STI studies in Africa attests to this, especially due to the lack of opportunities for postgraduate studies.

In most African countries poor linkages between universities and public research institutes weaken the level of interaction with this important aspect of the operationalisation and effectiveness of the Regional Innovation System.

For instance, until late 1970s, the Nigerian Institute of Social and Economic Research (NISER) had a special link with the University of Ibadan⁹ whose council appointed NISER staff on terms of service similar to those enjoyed by staff of this University. However, Decree No. 70 of 1977 severed this useful linkage. NISER then moved out of the University Campus to its own permanent buildings as a full-fledged Research Institute. NISER started its unit on Business and Technology Management during the 1980s. In Ghana, the Council for Scientific and Industrial Research (CSIR) has a Science and Technology Policy Research Institute (STEPRI), which was created in the early 1990s, but its impact on generating and disseminating STI indicators and data has been limited in the past. STEPRI is one of the designated National Focal Points for the NEPAD ASTII Initiative in the country.

Thus, there is a major challenge facing the African STI scholarly community (including those outside the continent) regarding STI studies in general, but recently STI Indicators data generation and dissemination, in particular. For instance, when South Africa's DST commissioned CREST and High Impact Innovation (HII), both in the country, to conduct a baseline study of the Science and Technology Systems of 22 African countries in 2006/07, it was very difficult to get appropriate information on some countries. Nevertheless, the reports produced for the DST are very significant because they have generated some interest, especially when the countries' studies became part of a bigger UNESCO Forum on Higher Education, Research and Knowledge project on 'Mapping Research Systems in Developing Countries' from 2006 to 2009.¹⁰ During both exercises, it was evident that more work has to be done, especially regarding the generation of STI indicators data in African countries, with the appropriate structures to communicate and disseminate research results.

There are more research centres and networks in South Africa based in the higher education sector than any other country on the continent. The institutes of development studies have limited programmes only or research in STI-related fields. In most African countries, STI studies centres exist outside the higher education sector with limited capacity for human resource capacity development locally. Moreover, based on the dates for which these centres and networks were established, it is reasonable to argue that they are relatively young compared with similar, but pioneering, centres such as

the Science Policy Research Unit (SPRU) at Sussex University, established in 1966 in the UK, and the Research Policy Institute at Lund University in Sweden or other young centres with a good number of researchers consistently focusing on research and innovation activities.

CONCLUSION AND POLICY RECOMMENDATIONS

Science, Technology and Innovation Policy Studies subfield of indicators production and dissemination continue to grow significantly in developed and emerging economies. Central to this growth is the demand for evidence-based policy making based on STI indicators data collection and analysis. Indeed the ever-growing interest in this field of research and innovation activity has resulted in different kinds of indicator generating community and the relevant clients. The level of analysis, the type of indicators, the consumers and their uses and the interrelationship among the different stakeholders is growing more complex every year. Increasingly, sectoral indicators are gaining importance with biotechnology, information and communications technologies, nanotechnology and higher education as some of the key areas.

Although national statistical agencies and research institutes have pioneered indicators development and production, with the rising interest in regional cooperation and integration, the survey and publication of regional STI indicators also gained prominence in the early 1990s, especially within the European Community and later in Latin America and South East Asia. At the same time multilateral organisations including the OECD and UNESCO still maintain interest in the generation and dissemination of comparable data on indicators.

Even though the availability of national STI indicators or sectoral indicators in most advanced economies may be taken for granted, in most developing countries it remains a major challenge. However, there has been gradual capacity building and production of indicators in some developing countries, especially the emerging or newly industrialising economies in Latin America and Asia. It is acknowledged that indicators development is not new in Africa, but the only major efforts come from South Africa and a few selected countries in North Africa despite some past international efforts at assisting some countries. What has been lacking is the individual national institutional capacity in the past in most countries. More often than not, there has not been continuity after externally-assisted projects related to indicators data gathering exercises end. The follow up continues to require external assistance rather than an endogenous system of indicator development. The limited number of the

countries with STI indicators generation capacity stems from the following observable challenges:

- First, there have not been any concerted national efforts to have such relevant information as part of national development planning in most countries.
- Second, national institutional and research capacity in this field has not been well developed.
- Third, national statistical institutions, which are pioneers in STI indicators data generation and management bodies in developed countries, have weak capacities in most African countries in terms of both human resource capacity and information and telecommunications infrastructure to support their activities.
- Fourth, the internal mobility of skilled personnel who were engaged in some STI indicators development and research capacity building process, but who often move to other agencies in different fields of research interest.

The launching of the African Science, Technology and Innovation Indicators Initiative programme (ASTII) under the auspices of AU/NEPAD Consolidated Plan of Action for Science and Technology is an attempt at providing evidence-based policy making instruments in the development and planning processes in Africa. However the ASTII is still in early stages of implementation.

To address the challenges on indicators development the following set of recommendations should be considered by the policy-making and research communities:

I. ESTABLISHMENT OF STI POLICY STUDIES CENTRES AND REGIONAL NETWORKS

One of the key recommendations of this article is the need for the establishment of, or strengthening of STI Policy Studies Centres and Regional Network of STI Indicator Producers at the national, sub-regional and continental levels in Africa. For instance, even though STI Policy studies is growing from strength to strength in advanced countries, within the European Union's Framework Programme the importance of network of STI Policy studies is highly recognised with the formation of PRIME under which the European Network of Indicator Producers project (ENIP) was launched. Meanwhile in Latin America, there exists RICYT. The 19 African countries and institutions participating in the first phase of the ASTII 'National R&D and Innovation Surveys' under the AU/NEPAD Consolidated Plan of Action for Science and Technology should be used as

the nucleus of such a regional network with room for future expansion of the membership.

II. PARTNERSHIP FOR CAPACITY BUILDING WITH ESTABLISHED RESEARCH CENTRE

To a large extent, the future of STI indicators development will be influenced by the general growth of STI Policy Studies on the continent. National capacities are however still lacking in many countries. In this light, the formation of appropriate training and research partnerships at postgraduate level with well-established centres of STI Policy Studies, especially those with expertise and programmes in indicators in the developed and developing countries is very important. Institutions such as UNU-MERIT, the Research Policy Institute at Lund University in Sweden and the UNESCO Institute for Statistics could provide initial support.

III. INCREASE AWARENESS OF NATIONAL STATISTICAL AGENCIES

National statistical agencies should take more interest in the generation and management of STI indicators data than they have done in the past. The appropriate policy and legal frameworks should be developed (where such legislations do not exist) to make STI indicators part of official national statistics.

IV. PROVISION OF ADEQUATE FUNDING SUPPORT

STI indicators development at the national and regional levels requires adequate financial outlays. African governments and institutions should make available budget lines in support of such activities. Although external support from the development partners remains critical, that should be considered as a short- to medium-term measure.

NOTES

- 1 The Frascati Manual was first published in 1964 when the OECD met with national experts on research and development statistics at the Villa Falcioneri in Frascati, Italy in June 1963 (OECD, 2002).
- 2 Although STI indicators are very useful, we are also mindful of the weaknesses of the inputs and output indicators.
- 3 PRIME brings together 51 institutions representing 65 research groups from 19 countries with some 200 active researchers and over 200 doctoral students mobilised by its training activities. http://www.primenoe.org/index.php?project=prime&locale=en&level1=menu1_prime_1b8057d059a36720_1&level2=1&doc=home

- 4 However, India first made efforts to produce R&D statistics in the mid to late 1950s, but early surveys could not provide reliable data.
- 5 RICYT was established in 1995 following the First Ibero-American Workshop on Science and Technology Indicators held in Argentina in 1994.
- 6 The FRD was transformed into the National Research Foundation (NRF) in 1999. The NRF is a major public research funding agency in the country.
- 7 This subsection benefited from Teng-Zeng F. and Mouton, J. 2006. 'National Innovation System in the Context of Socio-economic Transformation in Africa', Background Paper for Africa PRIME Workshop held at CIRCLE, Lund University (Sweden), 23rd–24th January 2006.
- 8 One of the objectives of the South African Research Chairs Initiative was to help turn Africa's brain drain into brain gain and by this award and appointment, TUT has facilitated this process in this important field of knowledge and human resource activity.
- 9 The University of Ibadan was the first university college to be established in Nigeria in 1948 with special relation with University of London.
- 10 The Forum's programme is concluded but the reports are available at: <http://academic.sun.ac.za/crest/unesco/site.html>

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Building Systems for Innovation ‘Take off’ in African Economies

Abdelkader Djeflat

SUMMARY

While catch-up theory assumes that innovation takes place in a linear model and that path dependant trajectory characterise the innovation process, ‘innovation take off’ rests on the premise that innovation systems need strong policy impulses from government for innovation to effectively take place. Innovation take off is the prerequisite for innovation systems to operate in a conventional manner. In many developing countries, innovation systems construction takes place in a very specific environment characterised by the rise of a small and medium scale enterprises (SMEs) sector but with little experience in the fields of R&D, relatively weak industrial performances in terms of productivity, and high level of obsolescence both in terms of human resources and equipment. While the approach in terms of innovation systems is real and attracts a great deal of attention from policy makers, very little work has been done on the way African countries could engage in a real take off policy of their innovation system in a sustainable manner. This contribution addresses the fundamental question of how innovation takes off in late industrialising countries such as African countries, both in terms of policies and conceptual framework. It draws from the Algerian experience and takes further the conceptual and theoretical approach that have been developed in earlier works on industrial technical centres as a way to trigger off innovation.

INTRODUCTION

While catch-up theory assumes implicitly that innovation takes place in a linear path and that markets play a key role, ‘innovation take off’ rests on the premise that innovation systems need strong policy impulses from government for innovation to effectively take

place. Innovation suffers from a real crisis, not a maturity crisis known in certain advanced crisis but a crisis of birth in the framework of an innovation life cycle to be determined. If National Systems of Innovation (NSI) in the developed world are considered to be in an advanced stage, those of the developing world are rather in a primitive stage (Gu, 1999).

Innovation take-off is the prerequisite for innovation systems to operate in a conventional manner. Innovation systems theory has long been characterised by the difficulty in using it in system construction (Lundvall et al., 2002), yet many less developed countries (LDC) seem to have resorted to this approach to build their innovation systems. Good examples are found among the BRICS countries (Brazil, Russia, India, China and South Africa).

In many other LDCs, like the Maghreb countries (Algeria, Tunisia, Morocco), innovation systems construction takes place in a very specific environment characterised by privatisation of public concerns, the rise of a strong small and medium enterprises (SMEs) sector, but with very little experience in the fields of R&D and innovation, and a relatively weak industrial sector in terms of performances, suffering notably from high levels of obsolescence both in terms of human resources and equipment.

While the approach in terms of innovation systems is real and attracts a great deal of attention from policy makers in these countries, many of them are seeking the best and quickest way to start off innovation notably in their industrial sector, looking at the advanced world experience and trajectories but more often at the BRICS experience. Yet when looking at these countries, where innovation is effectively taking place, a variety of situations and trajectories exist.

This article addresses the fundamental issue of innovation 'take-off' in late industrialising countries such as the Maghreb countries, both in terms of policies and conceptual framework. The issues raised relate to innovation dynamics in the early stage of system construction and notably: What are the characteristics of innovation in the pre take-off stage? How do African countries compare with emerging countries and the advanced world? How does take-off relate to catch-up and to what extent is it more relevant to African countries than catch-up? Innovation systems at the take-off have special characteristics and notably have their own trajectories: what are they and do they help the construction of innovation systems for take-off? This raises two fundamental issues: firstly, what are the modes of construction of innovation systems in the take off stage and what steps can be figured out, and secondly, what is the driving engine for innovation take off?

The article is an outcome from a major work conducted in 2007/2008 for the European Union (MEDA II) to support innovation systems building in Maghreb countries. It consists of five sections: section 2 discusses the concepts of innovation take-off, and how it relates to the catch-up approach;

section 3 concentrates on the modes of construction of innovation systems in the take-off stage; section 4 examines industrial technical centres as possible engines for innovation take off; and finally section 5 draws some conclusions.

INNOVATION DYNAMICS AT THE TAKE-OFF STAGE

THE NECESSARY TAKE-OFF STAGE IN INNOVATION DYNAMICS

It is a fact easily documented that major efforts have been made by a number of developing countries to launch innovation, pressurised as it were, by innovation based competition. It is also a fact that innovation output remains relatively poor in these countries. All kinds of indicators such as R&D expenses as percentage of Gross Domestic Product contribute to show that. Some factors, listed below, can be used to explain this situation.

Technological backwardness of Africa compared to other countries: As noted elsewhere, many countries, including the developing ones, remain low R&D performers and continue to lag behind on other aspects of great relevance for creation and exploitation of knowledge in the contemporary world (Fagerberg et al., 1999; Fagerberg and Godinho, 2004). The gap is clearly shown when looking at conventional indicators. The number of scientists in R&D in sub-Saharan Africa in 2001 reached 3,193 individuals, which amounts to 0.3 per cent of the total number of researchers in the developing world and 0.1 per cent of the total number of researchers in advanced countries (see Table 1).

Table 1 State of R&D in the world (2001)

Countries and Regions	Number of Engineers involved in R&D	Total R&D (%GNP)	Performance (%): Production sector	Performance (%): Higher education
Developed countries	2 704 205	1.94	53.7	22.9
Developing Countries	1 034 333	0.39	13.7	22.2
Sub-Saharan Africa	3 193	0.28	00	38.7
North Africa	29 675	0.40	NA	NA
Latin America	107 508	0.45	18.2	23.4
Asia (excluding Japan)	893 957	0.72	32.1	25.8
World	4 684 700	0.92	36.6	24.7
Note NA: Not Available				

Source Lall and Pietrobelli (2003)

Moreover, R&D funded by companies in East Asia is 250 times more than in African countries (not including South Africa), 25 times more than in

Latin America and twice more than in transition economies. There are very limited R&D expenditures in Sub-Saharan Africa and the situation does not seem to have improved significantly as a whole at the beginning of the year 2000 (Economic Commission for Africa, 2004).

Limited absorption capacity

Major efforts were made, however by some countries in recent years to boost R&D and expenditures increased in a relatively short time from 0.3% to 0.7 per cent, and even to 1 per cent of GDP, notably in North Africa (Djefflat et al., 2007). Often this effort associated with some kind of policy has not produced any significant result showing that, financial thrust, by itself does not get innovation off the ground within a reasonable time. On the contrary, too much funding has created some undesirable side effects. Thus one of the important problems is the 'absorptive capacity' of these countries.

Table 2 Planned and allocated budget in the five-year period from 1999 to 2003 in Algeria (in Dinars – billion)

Budget	1999	2000	2001	2002	2003	Total
Planned budget	21.15	31.21	33.66	36.38	36.38	158.78
Effectively used budget	5.1	4.1	5.1	4.6	5.6	24.5
Used/planned (%)	24.11	13.13	15.15	12.64	15.39	15.43
Note 1US\$ = 74 Dinar						

Sources National Syndicate of Researchers (2006), cited by H. Khelifaoui *Les technologies de l'information, politique de recherche et d'innovation et politique scientifique*, Report to the Ministry of Urban Planning and Environment, Algeria, p. 12; Note: 1US\$ = 74 Dinars.

As shown in Table 2, less than 16 per cent of the allocated funds in Algeria could be absorbed by the national research system. Many factors could explain this (Djefflat et al., 2007). The first, relates to the weakness of the human element, which remains a key element, coupled with a poor institutional and incentive regime. FTE (Full time equivalent) researchers mobilised represents less than 10 per cent of what could be mobilised. Thus all ingredients appear to exist without the expected performances, unlike in advanced countries where similar effort would have yielded satisfactory results. Critical mass, defined as the minimum level required of a mix of human, financial and institutional ingredients, appears to be one of the key issues. The importance of absorptive capacity has been highlighted in several contributions as a complementary necessity to knowledge creation in relation to technologies acquired abroad (Mowery and Oxley, 1997; Kim, 1997), as a prerequisite to the learning process at a firm level, which necessitates notable intangible investments (Cohen and Levinthal, 1989), and as capacity to create new knowledge and to search and select the most appropriate

technology (Narula, 2004). This lack of absorptive capacity on the part of firms could also be the result of the lack of applicability of technological knowledge to local conditions, making collaboration with underdeveloped socio-economic structures virtually impossible in a non-system perspective (Szogs, 2004). The difficulties met reflect the crisis which the national absorption capacity shows. This can be identified with several factors (Narula, 2004): weak or missing basic infrastructure, (means of communication, electricity, health, and basic education), advanced infrastructure (universities, research institutes, firms-domestic and foreign affiliates) and formal and informal institutions (intellectual property rights regime, taxation, incentive system and partnerships). It is also a characteristic of the difficult take-off which raises slightly different issues than the catch-up problem.

The problem in sub-Saharan Africa can be better highlighted by comparing the countries in the region to a newly industrialising country such as South Korea. Figures show a relatively high absorptive capacity in terms of R&D expenditure, in this case, leading to a successful take-off of its innovation system. In terms of industrial research, South Korea is in the sixth place among OECD countries,¹ with R&D expenditure reaching US\$14.43b per year. Globally, industrial R&D reached 2.64 per cent of GDP in 2003 (see Table 3). In more details, enterprises account for 70 per cent of the total R&D expenditure: half of these come from the electronics sector, followed by the automotive (14.8%) and chemical industries (10%).

Table 3 Industrial R&D expenditure as a percentage of GDP in South Korea (1970–2003)

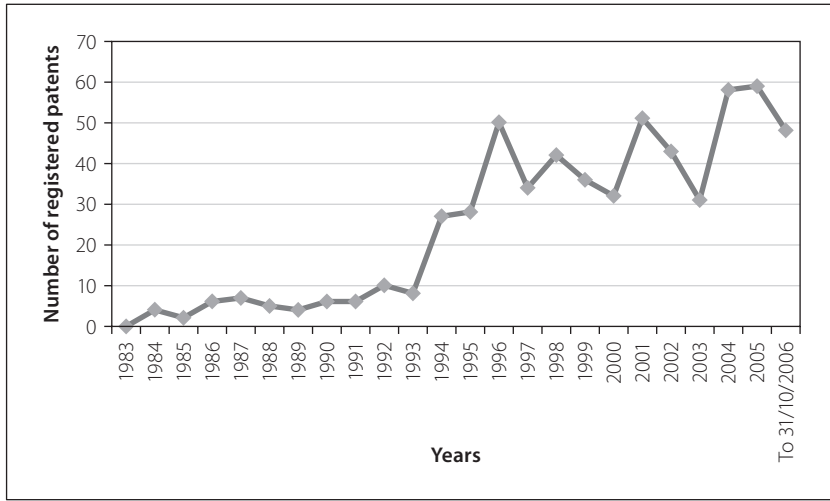
Years	Percentages	Years	Percentages
1970	0.39	1997	2.48
1975	0.42	1998	2.34
1980	0.56	1999	2.25
1985	1.52	2000	2.39
1990	1.87	2001	2.59
1994	2.44	2002	2.53
1995	2.37	2003	2.64
1996	2.42		

Source Ministry of Science and Technology & Korea Institute of Science and Technology Evaluation and Planning (2004) cited by Jay-Ik Choi, Vice President of the Korean Industrial and technological Association: les activités de R&D dans les entreprises Coréennes, ANRT Répères sur l'innovatin en Corée, Paris.

Weak irregular and uncertain R&D result

As noted elsewhere, several African countries have relatively weak R&D results and are weak on the creation and exploitation of knowledge in the

Figure 1 Evolution of the number of registered patents by residents in Algeria



Source Djeflat et al., (2007)

contemporary world (Fagerberg et al., 1999; Fagerberg and Godinho, 2004). Figures from the Algerian Patent Registration Office show the weak performances of R&D and the relatively slow and difficult progress that has been made. These are signs of the difficult take-off of innovation performances as shown by the number of registered patents by residents. The peak reached in 1965 did not exceed 60 patents. During the ten years between 1983 and 1993, there were less than 10 patents on average registered each year (Figure 1).

Comparatively in South Korea, the total number of registered patents has been growing at a relatively high pace, having grown by 100 times between 1981 and 2000 (see Table 4). The number of registered patents in the United States Patent Office (USPTO) jumped from 943 patents in 1994 to 3 944 in 2003.

Table 4 Number of registered patents in South Korea (1981-2000)

Patent Type	1981	1985	1990	1995	2000
Total Number of registered patents (T)	1 808	2 268	7 762	12 512	34 956
Patents registered by Koreans (K)	231	349	2 554	6 575	22 943
K/T (%)	12.8	15.4	32.9	52.5	65.6

Source Korean Intellectual Property Office, cited by Yim D. S. (2004), *Korea's National Innovation System and the Science and Technology Policy*, Science and Technology Policy Institute (STEP), p. 10.

Furthermore, the difficult take-off of the innovation system is corroborated by the high proportion of individual innovators, which represent 84 per cent of the total, while the share of enterprises did not exceed 9 per cent (Djeflat et al., 2007). Research centres and universities also lag behind with only 6

per cent, showing a real crisis of institutional research. This is also the syndrome of stagnation, i.e. pre take off. In comparative terms, in France the proportion of institutions reached 68 per cent while the share of individuals did not exceed 16 per cent – another indicator of an innovation system in the stage of maturity.

FROM TAKE-OFF TO CATCH-UP

The take-off stage stems much from the take-off theory of Rostow (1960). Various critics have long pointed out the main weakness of this model, namely its linearity and we would go along with this, knowing that standard theory has largely failed to convey the complex and interactive nature of the innovative activities. One can argue in this particular case that take-off is not at the beginning – but at the end of a complex process, whereby preliminary conditions incorporate a set of physical, financial, human, and institutional as prerequisites for innovation to take place, but also, from an evolutionary perspective, complex, cumulative and path dependant interactions. These preliminary conditions need further clarifications. The experience of industrialised countries show that they benefit from rich learning interactive spaces in the sense that several productive encounters take place between those that need knowledge and those that could interact with them. Countries in the South can have only poor learning interactive spaces as a result of the scarcity of these interactions (Arocena and Sutz, 2003). NSI functions in the wake of diversity and variety (Johnson, 1992), of uncertainty resulting from their evolution according to a selected trajectory, selectivity and path-dependency or historicity and finally of irreversibility (Niosi et al., 1992). It is interesting to raise the question at this stage of the relevance of catch up theory for these countries.

Catch-up, while being appropriate for several emerging countries seems of little relevance in a context where innovation is largely inaccessible and where the innovation take-off is still problematic. Similarly, catch-up appears more appropriate to the process of catching up world leaders (Johnson and Lundvall, 2003), which is remote from the preoccupations of the majority of African countries with the exception of South Africa where performing industry exists (Avnimelech and Teubal, 2006). Catch-up theory presupposes implicitly the existence of a structured, complete and fully operational NSI. Reality shows that we could not assume the existence ex-ante of NSI and the limited work done on Africa give little evidence of its existence. Often NSIs exist in a preliminary form, are unstructured, disorganised and fragmented. For example, studies on North and West Africa show the existence of uncoordinated components largely disconnected from public policies (Djefflat 2003, Casadella 2006, Carré 2002). Similarly,

sectorial innovation systems cannot be assumed *ex ante* as shown in studies in the agro-food industries in North African countries (Ait Habouche et al., 2004) knowing that this is a prerequisite for catch-up to take place (Avnimelech and Teubal, 2006).

Catch-up implies the existence of effective demand for R&D and innovation services while reality shows that this demand remains very weak in spite of the opening of these economies and the pressure of competition. Development of a firm, a regional or a national innovation system could not possibly evolve unless a substantial demand exists for new products and services and subsequently for R&D activities (Nielsen, 2005).

Take-off appears to be more appropriate for several reasons:

- Firstly, it is more adapted to the current state of economies where innovation systems are still in the construction stage in which most African countries are (Muchie et al., 2003), characterised mostly by incomplete NSI, weak or missing links and weak incentive systems (Narula, 2004, Djeflat, 2004). They suffer from a deficit of interactions between the main components (Casadella, 2006) and pronounced rent-seeking on the part of the main actors (Djeflat, 2004) to the extent that they can be considered as nonexistent (Arocena and Sutz, 2003).
- Secondly, it put the emphasis on the necessity for certain preliminary conditions to reach a critical mass required for the take off to take place. Consequently, take-off is more appropriate in the sense that system construction requires that certain conditions are fulfilled. Among these, the creation of learning capacities appears to play a key role in a bottom up strategy (Casadella, 2006).
- Thirdly, take-off appears to be a vital stage in the emerging countries that have evolved in the superior stage, which is catch up stage. This can be seen in Brazil, China, South Korea and India. Finally, take-off stage needs a strong state support particularly regarding the institutional dynamics in terms of regulations, salaries and incentive systems, public procurements, and so on, while the conditions of market dynamics are being put in place in transitional economies such as Maghreb countries for example. This is the reason we talk about system construction or promotion (Lundvall et al., 2002) as a substitute to its *reproduction*, which is more appropriate for emerging countries.

CHARACTERISTICS OF INNOVATION SYSTEMS IN THE STAGE OF TAKE OFF

Unlike NSI of the North, innovation systems in the South cannot be assumed to have similar characteristics (Edquist, 1997). The diffusion of the

NSI concept in the South is possible only if two requirements mentioned previously are fulfilled and well understood: the character ex-post of NSI and the construction of technological capacity. This gives NSIs in the South their own specificities and the heterogeneity of their trajectories, and explains to some extent the various stages of development they have reached. While innovations in the *high-tech* sectors are relatively sophisticated and based on science and radical innovation, NSIs in the South reflect routine perspectives of techniques, where learning by using predominates, R&D activities are not clearly defined and formally articulated within enterprise strategies (Arocena and Sutz, 1999; 2002). Problems of vulnerable and unstable macroeconomic environment are also quite important (Cassiolato and Lastres, 1999) and constitute real obstacles for innovation to the extent that we could talk about *national system of inertia* (Hobday 1995; Hobday et al., 2004). Networks between industry and R&D tend to be absent (Wangwe, 2003). The inability to put in place mechanisms of collective learning is a marked feature, knowing that without collective learning, it is difficult to talk about the existence of innovation system (Archibugi et al. 1998). In this respect, the innovation gap as defined by Arocena and Sutz (2000), goes beyond access to technological know-how and entices three fundamental problems (Oyelaran-Oyeyinka, 2004). The first one is the inability of local institutions to interact with productive entities in order to guarantee a sufficiently autonomous technological dynamics. The second one relates to the difficulty in the building of local knowledge through the tacit knowledge of small African structures which are unable to face new needs in an unstable competitive environment. The third one relates to the repetitive techniques of learning through imitation, leaving relatively little room for opportunities to renew and modernise enterprises' knowledge. Local knowledge is used by institutional actors in charge of the promotion of real endogenous capabilities. Finally NSI in the South are relational, normative and built ex post (Arocena and Sutz, 1999; 2002),

While trajectories constitute a key concept in the catch-up theory (Malerba, 2004), in take-off approach, they take a particular meaning. Trajectories in African countries do not seem to be continuous and linear. They are often broken trajectories of sectors which accumulate know how and knowledge, which manage the process of gathering the necessary conditions for take-off but manage to regress, and de-accumulate through de-learning. The sources of de-accumulation are numerous: instability of competencies, and relatively high and continuous labour and employee *turnover* (Oyelaran-Oyeyinka, 2004), the attractiveness of more lucrative sectors often in the tertiary sector, the exodus of competencies and the effects of structural adjustment programmes. The latter have been major factors of de-accumulation as a result of dismantling numerous public enterprises in

the manufacturing sector and the laying off of their employees (Djeflat and Boidin, 2002; Djeflat, 2004; Casadella, 2006).

The declining investments in industry as a result of falling external revenues has contributed a great deal to these broken trajectories. This interrupted learning process helps to explain the weaknesses of learning and managerial capacities in the strict sense of the word (Lall and Pietrobelli, 2002; Johnson and Lundvall, 2003). Liberalism also derives from making less effort in R&D to benefit from ready-made technology due to more open economy and additional facilities for importing (Naclerio, 2004). This is not to be assimilated to what Johnson (1992) calls de-learning, the capacity of forgetting (Mytelka, 2000) so indispensable to technical change at the firm level. Competition for local resources coming from basic and more urgent needs in terms of health, food and basic infrastructures contribute also to adjourning or marginalising research and innovation programmes and policies. Finally, 'rent-seeking' which characterises many African economies tends to strengthen existing structures and practices, leaving very little room for creativity, invention or innovation.

Consequently, two major conclusions can be drawn: the first one, is the need to construct an innovation system more appropriate to the take-off stage whose main characteristic is to exercise a relatively strong push for an effective demand for R&D products and services to emerge; and the second one is the necessity to build an innovation system which could move the whole apparatus from take off to catch up at a latter period.

MODES OF CONSTRUCTION OF INNOVATION SYSTEMS IN TAKE-OFF STAGE

The absence of structured and functional NSI in LDCs has been highlighted in several contributions partly as a result of building them ex post (Lundvall et al., 2002; Casadella, 2006; Carré, 2002; Djeflat, 2003). Similarly, several attempts are made to characterise a more appropriate way to build innovation systems which can be considered sometimes as a substitute and at other times as an intermediary stage prior to the building of a full-fledged NSI. Of these, we can identify from the literature notably National System of Science and Technology (Masinda, 1998), National System of Technological Learning (Viotti, 2002, 2003), National System of Technological Capacities (Lall, 2000), National Capacity of Absorption (Narula, 2004), National Technological System (Lall and Pietrobelli, 2003), National System of Innovation and Construction of Competencies (Lundvall et al., 2002; Muchie et al., 2003), National System for Development (Edquist, 2001), National System of Construction of Competencies (Casadella, 2006) and finally Technical Support System For Technological Innovation (Djeflat, 2006).

STEPS IN THE CONSTRUCTION OF NSI IN THE TAKE-OFF STAGE

While a systematic approach in the construction of NSI could not be identified in the take-off stage in the literature, there are components in some approaches, which could help figure out stages in this construction process. Three approaches can be briefly mentioned:

- In the first one, a descriptive model links construction process to stages of development (Liu and White, 2001). Six activities related to the innovation process are identified: research, production, interactions, coordination, control mechanisms and education. Their analysis rests on the distribution of activities in the innovation dynamics. Liu and White (2001) apply this method to analyse the Chinese NSI throughout the various stages of development and highlight differences in the institutional framework, in organisation and in performances of NSI of Communist China and Democratic China.
- A second approach which goes along these lines has recently been put forward (Casadella, 2006) which identified four stages:
 - Stage 1: non action in the pre take-off stage, a non-system perspective (Szogs, 2004).
 - Stage 2: decentralised improvement of knowledge – *National System of Construction of Competences* based on the mobilisation of local knowledge, and use of knowledge in the perspective of improving learning capacities and guaranteeing of learning effort (Casadella, 2006).
 - Stage 3: Centralised improvement of knowledge through NSI in the broad sense, where Technological Learning (Viotti, 2002) involving diffusion of foreign technology, preliminary R&D and other efforts of technological learning take place.
 - Stage 4: Knowledge creation through NSI in the strict sense of the term accompanied by the creation of new knowledge and full-fledged R&D activities.
- A third approach takes into account the various intermediary stages:
 - Stage 1: pre take off stage characterised by a *national system of inertia* (Hobday, 1995; Hobday et al., 2004).
 - Stage 2: creation of learning capacities through bottom up strategies (Casadella, 2006) and adequate learning interactive spaces (Arocena and Sutz, 2003).
 - Stage 3: creation of national capacity of absorption (Narula, 2004).
 - Stage 4: completion of the National System of Construction of Competencies (Casadella, 2006).

- Stage 5: Technical Support System for Technological Innovation (Djefflat, 2006).
- Stage 6: finally a full fledged innovation system.

These approaches are tentative and they need further exploration and greater analytical depth from a theoretical point of view. They also need solid empirical investigations that are specific to African countries, taking into consideration their specificities but also the variety of situations we come across on the continent.

THE DRIVING ENGINE FOR TAKE-OFF

While the various stages for take-off are important for understanding the mechanisms, the driving force behind take-off is of utmost importance. Indeed take-off would not occur unless an important driving force is in place as in the case of emergent countries. There are several elements which could play this role. Of these, three major elements can be indentified: the guarantee to innovation effort, public procurement and industrial technical centres.

The guarantee to innovation effort: the development of learning capacity and the acquisition of technological capacity are closely related to the opportunities to apply these capacities to solve technical and technological problems (Casadella, 2006). These opportunities are fundamental to develop innovation capacities (Arocena and Sutz, 1999). Indeed if opportunities to build an appropriate, tailor-made and context specific solution to local problems, are not given, it would be difficult to get innovation off the ground. Several examples exist in the industrial experience of African countries and particularly those that have access to surplus income to resort to foreign companies, design offices, laboratories and centres of research for any kind of problems faced, missing valuable opportunities for local innovation capabilities. In other words, innovation take-off cannot be triggered off through conventional market mechanisms, but needs a relatively strong institutional support made of a robust legal system, a good incentive system, and political engagement on the part of actors of the innovation set-up (Lundvall, 1992; Von Hippel, 1988). Thus a guarantee to innovation effort is necessary. This effort is made by individuals and institutions at various levels: micro-, meso- and macro-economic.

Public procurement: Public procurement can play a vital role in the face of market failure in the take-off of innovation system. It is acquiring more and more importance both as a policy instrument and a concept to be further investigated (Edquist et al., 2000). The actions of government were critical in the emergence of innovative technologies and services in most advanced

countries. Public demand for knowledge and innovation exist even in the prospect of privatisation. Innovation projects need a broad range of products and services, and an important capital lay out. The role of the State is paramount. This role is even more important in African countries where the technological base of the private sector is relatively weak. The State plays an important push role before the private sector and market become strong enough to take over. A public- private partnership to build this sustainable demand for innovative products is also a key to this process.

INDUSTRIAL TECHNICAL CENTRES AS ENGINE FOR TAKE-OFF

Industrial Technical Centres (ITC) appear to play a significant role in innovation take-off particularly for SMEs as shown in recent contributions (Devalan, 2006; Djeflat, 2008). Their main aim is to cater for specific technological demands from industry which is usually heterogeneous – composed of SMEs and big firms. SMEs usually have relatively little means to allocate funds to proper R&D and also to testing and control, which require relatively high investments and competencies. In industry where the majority are big concerns, there may be less need for ITCs, knowing that they usually are well endowed with funds, human competences and accumulated experience, proper R&D facilities and proven innovative activities. Basically, ITCs constitute valuable entities for technology transfers which have both human capabilities and material means in terms of finance and equipment to cater for specific needs of a company, an industry or a sector.

The success of ITCs rests mainly on their link position, which is relatively unique and the notion that ‘the industry network is more than the sum of the capabilities of firms’ (Foss, 1999). ITCs are the result of a partnership between the public and the private sectors at the crossroad of research and industry. They are also at the crossroad of several disciplines as ‘technology assemblers’ capable of analysing, adapting and transferring useful technologies for the design of new products or methods of production. Finally, ITCs constitute a national network located in between regions.² It has been frequently underlined that those institutions can go well beyond firms or industrial agglomerations (Lundvall, 1992; Kirat and Lung, 1999; Maskell, 2001). The major difference between ITCs and consulting or industrial services bodies is that the latter are capable of undertaking studies for the profession as a whole to upgrade technological capabilities and the way they are financed by members of the profession.

It is also suggested that the potential of ITCs for learning can be linked to their role as providers of services partly duplicating those provided by or in some firms. According to Mota and De Castro (2003) –

Some similarity of capabilities in specific areas can help to maintain a great proximity to and relevance for the context in which firms operate, and thus facilitate the processes of dissemination of knowledge in the industry. It also suggests that the motivations and benefits perceived by firms and, in general, the relevance of sharing experiences in this context should be seen in the context of firm's specific and idiosyncratic trajectories. The involvement of firms in technological centre activities may be a means for them to directly or indirectly access the experiences of other firms and individuals in an industrial system. The potential for generation of benefits may be associated to the perceived or real similarity between the activities that may be accessed through those centres and those carried out within the firms themselves, especially the activities that are perceived as most relevant in the context of their relationships with their clients and or suppliers.

Three central roles of institutes are highlighted: they are a learning partner for industry, they help to increase absorptive capacity, and they constitute a flexible repository in the innovation system by helping firms in peak periods and by reducing the pressure on universities through assisting in teaching and supervision.

Their inscription at the local and territorial level gives them extra closeness to university and higher education system as a whole and thus they are part of the National Innovation System.

Some of the services rendered may not be classified as R&D activities, but at the take-off stage, they can be considered as important by-products and complementary services to R&D. In this respect they contribute to broaden the span of NSI activities at this stage, to include non traditional and non conventional, yet vital activities for innovation to effectively take place.

As shown in other contributions, ITCs can be considered to possess 'unique' competencies and hold high quality which drives firms that lack skills, capacity in R&D and equipment to conduct in-house R&D projects to use them (Nerdrum and Gulbrandsen, 2007): ITCs constitute, in this respect an important contribution to firms in their search for innovation. Their contribution rests on their major tasks: they represent a *learning partner* to enterprises. Learning happens primarily through collaborative projects, collective R&D, public programmes oriented towards general interest. Secondly, they contribute to increasing *absorptive capacity* or to overcoming problems of low absorptive capacity of current national research systems, which is a fundamental component of the National Innovation System. While this dimension has not yet been investigated in depth, this author could conclude, like Nerdrum and Gulbrandsen (2007), that it occurs through two mechanisms: one is through the numerous

projects and personal contacts established between industry and the centre's staff and the other through the relatively high staff turnover which they experience and which benefits industry, consultancy offices et cetera. Third, ITCs have a *lubrication* or *intermediation* role in the research and innovation system. They have close relations to higher education, namely through joint laboratories and joint projects. This gives them the possibility to act as a buffer zone between universities and industry with the beneficial effect this produces, and also play an intermediation role between the two. They can therefore help SMEs of the private sector in particular increase their capacity for R&D by acting as a *flexible repository* in the national innovation system.

In Europe, industrial technical centres are found in France, Belgium and Spain. France plays a leadership role in this respect and has been particularly active in terms of the number of patent applications. It was ranked fourth in the world in 2006 and fifth in the world in terms of the size of R&D spending – behind USA, Japan, China and Germany. In all, 17245 patents were nationally registered in 2006 mainly by institutions – on top of individual applications. An average of 80 000 patent applications is lodged each year at the INPI (Institut National de la propriété Intellectuelle). Part of these applications come from ITCs. This requires anticipating industrial needs, the conduct of collective R&D projects, the diffusion of technological know-how and the transfer of R&D results to industry.

Most of the ITCs were created between 1948 and 1964³ and their original mission was to provide support to the industrial sector, made up to a large extent by SMEs. Their legal framework was recently integrated into the Research Law, putting thus emphasis on their R&D function⁴. They constitute the first Applied Research Network in France and have been providing for the last fifty years a set of expertise to SMEs which they would not otherwise acquire individually in the fields of R&D. In their role as an intermediary institution, between the world of research and that of enterprises, they play the role of facilitators, the exchange of information, the acquisition of know-how and the diffusion of technological progress and technology transfer. ITCs represent nowadays 4500 collaborators, 50 per cent of whom are engineers, scientists, and managers,

Intensive exchange occurs between ITCs and both industrial entities and universities. Thus annually, 200 theses are passed and 50 post-doctoral studies are supported on top of 200 contracts with public laboratories.

ITCs appear to have several attractions to Maghreb countries and indeed to LDCs as a whole (Lachat, 2004). Firstly, they are heavily based on incremental innovation and applied research, which in the case of innovation take off, represent the bulk of innovation needs. Breakthrough and radical innovation appear at this stage non feasible. Secondly, innovation take off

is the most delicate task when it comes to SMEs of the private sector. In other words, experience has shown that ITCs are particularly suited for R&D and innovation for the small scale industry. Thirdly, innovation take-off has to occur often in situations where NSIs are incomplete, unstructured and yet to take full shape (Djefflat, 2003). ITCs appear to be particularly suited for this type of NSI. Fourthly, ITCs cater, as seen earlier, for collective R&D and innovation needs of small enterprises. They can thus constitute a relatively good substitute for the lack of capabilities and means that SMEs suffer from particularly in LDCs and specifically in the Maghreb countries.

CONCLUDING REMARKS

In this article, an attempt is made to set the basis for the issue of innovation take-off both as a concept and as a policy instrument. This is in response to the issue of catch-up, which concerns a limited number of countries, namely the emerging ones. In a situation of de-structured, fragmented, immature and sometimes virtually non-existent NSI, in which most African countries find themselves, it would be difficult to work out catch-up strategies. Several attempts are being made to build innovation systems, inspired by those in advanced countries. These attempts are centralised and state-supported and take very little account of the creative potential of these countries, which are largely decentralised in nature, hence the very limited results obtained. This is an indication that innovation strategies built on the catch-up paradigm may not be totally appropriate in the current stage of development that many African countries are.

The take-off paradigm proposed in this paper takes into account this largely decentralised creative potential and the effective capacity to mobilise knowledge resources, and to exercise a sufficiently powerful thrust for innovation to take place through the emergence of effective demand for R&D. This approach incorporates implicitly the gathering of the necessary conditions for catch up at a later stage. The stages for innovation take-off need to be further examined both theoretically and from an empirical point of view. They need to take into consideration the specificities of countries, knowing that take off is context specific and strongly localised, even if common elements such as effective demand, public procurement and guarantee to the innovation effort exist. In African countries, the weakness of the private sector and market imperfections place responsibility on public procurement to get innovation systems to take-off.

Decentralised mechanisms such as industrial technical centres could constitute an appropriate mechanism to help the state action in its take-off strategy, even if they suffer from a large deficit in terms of academic

research. They have many interesting features of NSI in the construction stage and could have a structuring effect on the rest of the innovation system. This is a research avenue to be further explored.

NOTES

- 1 Jay-Ik Choi, Vice President of the Korean Industrial and Technological Association, the R&D activities in the Korean enterprises, ANRT, Paris, March 2004.
- 2 Extract from the White Book on ITCs, the ITCs Network, 2005, (France).
- 3 Law of 22 July 1948.
- 4 Research (Art. L. 342-1 à L. 342-13).

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Innovation in Africa – Toward a Realistic Vision

Bengt-Åke Lundvall

INTRODUCTION

Less than forty years after Rosenstein Rodan's (1943) seminal article that started the era of 'classical development economics' Hirschman (1981) gave an address where he recognised that the era had come to a close. Hirschman pointed out that he and his colleagues had overestimated the power of their ideas to overcome underdevelopment and he specifically referred to a lack of respect for the emotions and culture of those who were expected to realise the ideas.

I believe that Hirschman was right, not least concerning the African experience, and this is one reason why I see the establishment of a strong research capacity on innovation and economic development within Africa as fundamental for the formation of strategies that can bring Africa out of underdevelopment. I see the start-up of this journal as one important step in this direction. I am therefore happy to respond to Mammo Muchie's invitation to contribute with some ideas for this first issue.

In 2000 I co-organised the Aalborg workshop on innovation systems in Africa with Mammo Muchie, who initiated the project. It was the first time that I was confronted with the challenge to apply ideas about interactive learning and innovation systems to the reality of the African continent (see Muchie et al., 2003). This workshop inspired the formation of the global network Globelics (www.globelics.org) and in 2005, we organised the third Globelics conference at Tshwane University of Technology, Pretoria, South Africa. Globelics is now preparing for the second time in Africa to organise the 7th conference in Dakar, Senegal, later this year. Some of the inspirations for this article come from browsing the many papers on innovation in Africa proposed for this international conference.

A REALISTIC VISION IS NEITHER A DREAM NOR A PLAN!

Africa has one beautiful and one ugly face. It is a beautiful continent rich in terms of natural resources and among its people generosity and friendship are abundant. However both the statistics and a closer look show a different, harsher side of African reality. Millions of children live in poverty and illiteracy, many with serious health problems. Disorder in the form of local wars and crime contribute to the misery of several regions within the continent. Africa has been described as ‘the scar on the human conscience’.

Is there any light at the end of the tunnel? The harsh reality seems to get in the way of well-intended strategies and plans. Assume that we design a plan based upon ‘classical development economics’. We might begin by stating that the only way to grow rich is to industrialise, increase the savings ratio and make major investments in infrastructure, business and people. We might look for ‘industrialising industries’ and give priority to investment in those. We might recommend that a period of import substitution and regional integration is either combined with or followed by export-led growth.

We would have to realise the absence of the most important prerequisites for the success of such a strategy: an efficient state and a culture with strong emphasis on educational attainment and entrepreneurial spirit. The states are not strong and efficient and the culture does not promote the accumulation, diffusion and use of scientific knowledge. This hypothetical scenario seems to confirm the pessimistic reading for Africa.

One of the problems with this analysis may be that its focus is upon *what is missing*. An alternative approach might start from *what exists*. We know for instance that most of the population in Africa still live from agriculture and husbandry. We also know that, not least in agriculture, there is a tension between science-based technical solutions and local traditional knowledge. There is also a tension between the kind of western individualism that spurs private capital accumulation and the collective responsibility in Africa, not only for the nuclear family but also for the extended family and members of one’s village.

We believe that a *realistic vision* needs to take these facts as starting points – neither wishing them away nor seeing them exclusively as something that should be transformed as quickly as possible in order to create room for respectively ‘industry’ and ‘modernity’ in the form of scientism and individualism. However the vision cannot ignore the fact that there is a need for radical transformation of society.

What should be the direction for such a transformation? In this article, I will start from the assumption that a systemic view with focus upon innovation, knowledge and learning brings insights that are useful when it

comes to specifying a realistic vision to overcome the general pessimism about the future of Africa. Rather than setting up a very complex and insurmountable agenda, I will concentrate on a few mechanisms that might open up new avenues of hope.

FROM THE KNOWLEDGE ECONOMY TO THE LEARNING SOCIETY

The starting point is that the assumption that knowledge is the most important resource and learning the most important process (Lundvall, 1992; Lundvall et al., 2006) is also valid for Africa. Second, we take into account that important elements of knowledge are tacit and that for all practical purposes the combination of explicit and tacit knowledge is fundamental (Lundvall et al., 2002).

We also recognise that while some learning processes are science-based and make use of codified knowledge, equally important, is experience-based learning (Jensen et al., 2007). The most important learning processes are interactive – they require that those interacting with each other have a common language for the communication. To overcome the uncertainty involved in the context of innovation, they also depend upon building mutual trust (Lundvall, 1985).

The competence to learn is critical to any society including Africa. By the competence to learn, we mean learning know-how through experience and through social interaction (Lundvall and Johnson, 1994). Formal education systems therefore need to give access both to relevant codified knowledge and to the competences necessary for life-long learning. The ideal education system is one that combines traditional teaching methods with methods that engage students in the solution of practical problems and that enhance social skills of collaboration and communication (Lundvall, 2008).

Different knowledge institutions may give different relative weights to traditional learning and problem-based learning. The strength of the innovation system will to a certain degree increase with the diversity of its knowledge institutions. In the case of universities diversification may be reflected in a combination of major classical universities (in the case of Africa, one major national or perhaps even only one major regional university in each of Africa's six sub-continental regions), numerous open universities and technical institutions and colleges with strong interaction between higher education and society and, finally, technological institutes without educational tasks and with exclusive focus upon diffusion of knowledge to specialised users.

Innovation may be seen as a process with knowledge both as input and output. The input is codified and tacit knowledge while the output

is constituted both by a concrete innovation and the enhancement of the competences of those involved in the interactive learning that is the basis for the innovation. Scientific information and R&D becomes more and more important for innovation in all sectors of the economy, including agriculture. But the same can be said about tacit knowledge and experience-based learning. As distance is suppressed and change becomes more frequent and rapid, individual and organisational learning becomes crucial for technical innovation (Jensen et al., 2007).

APPLYING THE LEARNING SOCIETY PERSPECTIVE TO AFRICAN DEVELOPMENT

Enhancing the knowledge base (both scientific knowledge and good practise know-how) for agriculture seems to be the most natural first step for an African strategy for development (Juma, 2008).

Here the innovation system approach is useful because it helps to understand that it is not narrowly focused only on investing in R&D and formal academic training, but also broadly about capability, learning, innovation and competence building systems for development or transformation. The quality of the relationships between knowledge expertise and institutions on the one hand and the competence of the users (farmers and herdsman) on the other will determine the impact of investments. Therefore, feed-back from users is fundamental for the advancement and efficient use of knowledge.

Therefore a strategy to revitalise the agro-industrial innovation system would involve three elements:

- Investing in the training of scientific and technical expertise that will be of direct and indirect relevance for agriculture.
- Investing in the training of farmers to enhance their capability to absorb and use new knowledge
- Building bridges and networks between the experts and the users.

The three elements are interdependent. To support bridge-building the training of experts needs to have strong elements of problem based learning and strong interaction with farmers during the education processes. Interaction with farmers will help experts to have a realistic idea about the farmers' culture and understanding of the world and will consequently make it possible to communicate 'alien' ideas from science in a form that is respectful and meaningful to the farmers. Land-Grant universities in the US are examples of institutions that combine academic teaching with extension services especially targeted at farmers (Graham, 1994).

Similarly, the training of farmers should aim at making them more open to science, technology and innovation expertise. Early contributions to innovation and entrepreneurship refer to the fact that absorption of innovations was much quicker and more successful in agriculture in regions where farmers had a higher level of education (Nelson and Phelps, 1966; Schultz, 1975).

Ideally the education should offer the farmers positive examples from the use of new methods and consider how the new procedures can be combined with traditional modes of production and distribution. Below we will argue that the Danish historical example of 'People's high schools' may be taken as one source of inspiration for expanding the education of farmers (Lundvall, 2002).

More direct forms of 'knowledge bridges' may be the establishment of local extension service stations that can draw upon formal knowledge institutions. Ideally these institutions should be shaped in such a way that they, without compromising their function to enhance the competence of farmers, are able to take into account local culture.

WHO CAN DO IT – THE STATE OR A NEW AGENCY?

We may believe that such an agenda should be realised by 'public policy' and by the state. In most positive examples of economic development the state has played a strategic role (Reinert, 1999). But given that the capacity of the state in most parts of Africa is quite limited, we need to consider if there are other agencies that may play a role, such as the global donor community (Juma, 2008), but the experience so far is that it has contributed more to foreign aid addiction than to development. While some NGOs contribute positively to development, none of these agencies seem to be able to play a central role in the transformation of the society.

There is a need to establish a new kind of agency. Here we could be inspired by the successful transformation of Danish agriculture in the second half of the 19th century. While the state played a certain role in transforming agriculture from being mainly crop-oriented to being animal-oriented, the most important driver was 'the farmers' movement' (Lundvall, 2002).

The priest Grundtvig formulated the ideology that gave direction to the organisation of farmers into cooperatives. One of the most important elements behind the successful cooperative movement was the diffusion of 'people's high schools' training farmers in economic, societal and cultural issues. They offered not only training in useful skills but also instilled self-confidence among the farmers and prepared them for taking active part in the democratic processes in the society (Lundvall, 2008).

It is difficult to see a positive future for Africa without a similar kind of popular movement based upon the fundamental ideas of diffusing and sharing knowledge. To inspire such a movement, there is a need for a new kind of moral leadership that makes an attempt to reconcile indigenous knowledge with modern science and technology. Hopefully an emerging community of innovation scholars could foster such a leadership in its own midst.

AGRICULTURE AND INDUSTRY

So far we have focused on agriculture. This may seem in conflict with the historical experience that industrialisation is necessary in order to establish sustained economic growth and to abolish poverty. Again Danish history is interesting. While many other economies developed industries based upon minerals and forestry, Danish industrialisation started from agriculture and Danish production and export specialisation remains a reflection of the link between agriculture and industry.

Agriculture constituted an important market for machinery for farming, slaughtering and dairying and as well as for chemical and biological industries. As productivity and income levels increased, markets for consumption good also expanded. The industries refining primary agricultural products became export oriented. Bacon and butter were the strongest elements of Danish export specialisation for almost 100 years. Cooperative ownership of the factories that refine the products was crucial in linking qualitative and quantitative progress in primary agriculture both to market needs and to scientific progress. The government supported agro-industrial development by building a specialised university focusing on the needs of agriculture and by financing standardisation institutes.

This strong interlinking and positive interaction between the different elements of the agro-industrial innovation system did not take place by itself. The organisational strength of the Danish farmers' cooperative movement was critically important for the success. In Africa there is a need for a similar driver in order to build the knowledge base both for primary agriculture and for the industries that refine its products and the industries that can deliver its inputs.

FINAL WORDS

In the realistic vision presented so far, I have overlooked many problems and issues that need to be addressed in order to make Africa a more attractive place to live and work. One fundamental issue is the tension between

organising, managing and administrative agencies at and between different levels: local, national, regional and continent-wide. The heterogeneous character of nation states and the potential for ethnic conflicts within them is a strong argument in favour of developing strategies at the transnational level – i.e. at the regional or continental level.

The optimistic view would be that Pan-Africanism as a mission and the African Union as an organisational framework could become vehicles to realise the vision presented here. To exemplify, the attempt to build a 'Europe of Regions' is a modest attempt to link local level interests to the continental in Europe.

We have overlooked other serious problems that need to be addressed. Health problems, environmental problems, including land erosion, child poverty and lack of access to primary education are specific issues that need to be addressed to make life better for the majority. Here we see a formation of a new cooperative agency as a potential vehicle to cope with these problems. An enlightened cooperative movement may be necessary to build and run schools, health clinics as well as to establish local infrastructure.

Not everybody will agree that the vision presented here is 'realistic'. True experts on Africa may characterise it as a rather 'naïve vision'. My counter argument would be that without a vision there is no hope and Africa deserves hope.

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Innovations Systems in Renewable Natural Resource Management and Sustainable Agriculture

A literature review¹

Laxmi Prasad Pant and Helen Hambly-Odame

SUMMARY

The innovation systems approach to renewable natural resource management and sustainable agriculture has been recognised as a new conceptual tool. However, there is a lack of systematic review of literature in this emerging field of inquiry. This review of over 100 relevant contributions concludes that there have been two major paradigm shifts in agricultural science, technology, innovation and development – from the transfer of technology approach to the various research and extension systems, and then to innovation systems. Innovation systems in agriculture have two major theoretical foundations – innovation systems in manufacturing, and various systems approaches in agriculture. The review revealed that it is imperative to establish a new generation of innovation systems research in renewable natural resources that integrates three apparently distinct fields of studies – environmental management, international development and innovation studies.

INTRODUCTION

Agricultural research and rural development has moved from technology transfer thinking to various systems approaches with varying degrees of integration of local and indigenous, and expert ways of learning and innovation, the latest concept being innovation systems. Scholarly discussion on the innovation systems thinking has been influenced by two bodies of literature: one in manufacturing under the work of Edquist (1997; 1999), Freeman (1987) and Lundvall (1992a; 2002), and the other in rural development and agriculture, such as the work of Biggs et al., (2003; 2004), Clark et al., (2001; 2003), Hall and Nahdy (1999), Hall (2001), Hall et al., (2001a; 2000; 2001b; 2003b), Sumberg (2005) and Temel et al., (2003). Recently the

innovation systems framework has gained substantial acceptance in international development discourse among a diverse group of stakeholders, including multi-lateral and bi-lateral donors, actors of national innovation systems, and local and indigenous communities.

Despite encouraging advancements in agricultural science, technology and innovation, the world has witnessed food crises time and again. The major causes of the 21st century food crisis are identified as climatic change and extreme weather events, environmental pollution and natural resources degradation, soaring oil prices and diversion of food grains to biofuels, and rising food demand, trade restrictions and commodity market speculations (Katz, 2008; von Braun, 2007). The impacts of the food crisis are most severe on vulnerable sections of society in both developed and developing countries that have a low level of adaptation capacity – local and indigenous as well as expert knowledge-based adaptation. Although the causes and consequences of the food shortages are increasingly apparent, solutions are contentious around the paradox of productivity and sustainability. This paper argues that neither productivity-focused interventions nor sustainability-focused interventions in the past have been helpful to generate social welfare, specifically poverty reduction and social inclusion in low-income countries, and thus it is imperative to revamp the conventional discourse on international development.

This paper first characterises the systems approaches to innovation for development, and then discusses two major paradigm shifts in renewable natural resources and agriculture, first from the technology transfer to research and innovation systems and second towards innovation system's thinking. Finally, research gaps are identified in the emerging literature on innovation systems in renewable natural resource sector, and specifically smallholder agriculture.

PARADIGM SHIFTS IN SCIENCE, TECHNOLOGY, INNOVATION AND DEVELOPMENT

Before embarking on the discussion of processes of innovation, it is important to understand how a paradigm shift takes place in science, technology, innovation and rural development. Here 'paradigm' is defined as a shared belief system or worldview. Thomas Kuhn (1962) differentiates between the transition through a paradigm and the transformation of a paradigm or paradigm shift. Transition through a paradigm involves adjustments to conceptual tools within a paradigm. When such adjustments are not enough to deal with contemporary, often intractable problems such as food crisis, an entirely new paradigm with a new set of tools is necessary. Specifically

in agriculture, we find two major paradigm shifts: (1) from the technology transfer to research and extension systems; (2) from the research and extension systems to innovation systems (Table 1).

Table 1 Key paradigm shifts in agriculture

Attributes	Technology transfer	Research & extension systems	Innovation systems
1. Approaches			
Science-society relationship	Science and technology are relatively independent of political and other social factors.	Research takes place in a historically defined social, political, economic, agro-climatic context.	Innovation takes place in a historically defined social, political, economic, agro-climatic context.
Trajectory of technological change	Specific, unambiguous (e.g., researcher, an innovator, extensionist, a carrier and farmer, an adopter).	Not an unambiguous, one-way progression. Multiple actors as a part of research and extension systems.	Not an unambiguous, one-way progression. Multiple actors as a part of innovation systems.
Treatment of time	Classification of a technology as modern and traditional (e.g., modern and traditional crop varieties).	A technology is made up of many old and new components.	A technology and innovation are made up of many old and new, often unknown, components.
2. Contexts			
Organisational structure	National Research Institutes, National Extension Institutes.	National Agriculture Research Systems, including extension and education systems.	National Agriculture Research Systems, including extension and education systems, and private sector organizations.
Institutional responsibility	Research and extension as the public sector business.	Need for public and private partnerships in research and extension.	Need for public and private partnerships for sector coordination.
Role of public sector extension	Technology dissemination. The release/control of information.	Systems management. Active participants in applied research.	Systems management. Potentially a central node among the wide range of nodes in an innovation system.
3. Social goals			
Policy environment	Rigid state of equilibrium between public and private sector; regulative policy instruments.	Flexible state of disequilibrium among various institutions, state's role as facilitator of research systems.	Flexible state of disequilibrium among various institutions, state's role as facilitator of innovation systems.
Role of a farmer	The end user of a technology.	An experimenter within research systems.	An expert innovator within innovation systems.

Source: Authors with reference to Biggs (1990), Thrupp and Althier (2001), Sulaiman and Hall (2002) and World Bank (2007).

TRANSFORMATION FROM LINEAR TO SYSTEMS APPROACHES

The technology transfer approach emphasises linear relationships between science and society. Examples of this paradigm were commodity programmes, such as crop specific research, technology development and extension advocated during the era of the *Green Revolution* (1960s and 70s). Focus was on the development of modern varieties of few major cereals, access to irrigation and use of chemical inputs. Standardisation of technology as a package of practices was the major effort of agricultural research and extension overlooking temporal and spatial variations in farming communities, their local and indigenous practices, and diversity of agro-ecological conditions. The diffusion of technological innovation was presumed to be a linear process: researchers working in modern scientific establishments as the producer of knowledge and information, the extension worker as carriers of information and the farmer as the ultimate adopter (Rogers, 2003).

Since the linear paradigm considers science and technology relatively independent of historical, social, political, cultural and other institutional factors, various systems approaches have emerged to integrate various types and sources of knowledge and innovations, including local and indigenous knowledge and practices (Biggs, 1990; Sulaiman and Hall, 2002; Thrupp and Altieri, 2001; World Bank, 2007). In addition to the historical, social, cultural and political factors, attempts have also been made towards integrating social and biophysical systems because innovation in renewable natural resources and agriculture depends on the interdependence of three major sub-systems – technological systems, social systems and biophysical systems. Addressing such interdependence would result in three major competencies in agriculture: (1) favourable agroecological conditions; (2) access to agricultural technology, such as a crop variety; and (3) a range of support services – credit, inputs, produce markets, processing facilities, insurance against risk of crop failure, and favourable institutional environments for life-long learning and innovation. However, learning-based competence of stakeholders are replacing the conventional sources of core competencies – agroecological comparative advantage and technological advancements – providing a rationale for a paradigm shift towards information systems approaches (Pant et al., 2008).

In response to the increasing acceptance of systems approaches, standalone education, research and extension institutes are increasingly required to operate as a part of a broader systems emphasizing broad-based public-private collaboration, involving formal sector actors and rural communities in the processes of learning and innovation. The role of public agricultural extension as an authority-in-charge of release and control of technology and information is also being revised as a systems manager and facilitator of

public-private collaboration, and community-based research and development interventions (Sulaiman and Hall, 2002; Sulaiman et al., 2005).

Various systems approaches appeared to guide rural and agricultural development, particularly in the context of low-income countries. We identify three major approaches: (1) systems approaches to technological innovations; (2) systems approaches to the diffusion of innovation; and (3) systems approaches to individual livelihood².

(a) Systems approaches to technological innovations in agriculture

Recognising the limitation of the linear paradigm of technological innovations, Farming System Research Extension (FSR&E) was proposed during the 1960s and early 1970s (Collinson, 2000). The major attributes of the farming systems approach, as it was initiated during the time, are engagement of an interdisciplinary team of practitioners, involvement of small farmers, appreciation of their knowledge and practices and use of small farms as the main unit of analysis. The work on FSR&E is characterised by systematic description of system goals, system boundaries, linkages, feedback loops, goal seeking mechanisms, diagnosis of problems, design of experiments, and evaluation of results (Collinson, 1987; Zandstra et al., 1981). The evaluation of experiments can result in three outcomes – either to reformulate on-station experiments to plan further cycle of on-farm research or to disseminate results through extension agencies (Collinson and Lightfoot, 2000).

Farming systems thinking has substantially evolved since its beginning in the 1960s. Two major paths of evolution are evident from the literature. First, it evolved in terms of system scale, performance criteria and target beneficiaries (Hart, 2000). In terms of scale, it changed from the original focus on cropping systems to crop livestock integrated systems in the 1980s and then at community and watershed levels in 1990s. In other words, FSR&E either has a predetermined focus on selected commodities, a whole farm focus, a natural resource systems focus including on-farm and off-farm activities, or a livelihood systems focus which includes on-farm, off-farm and non-farm activities (Norman, 2002). Similarly the original focus of *productivity* as a system performance indicator had been modified to include stability in the 1980s and then further included *sustainability* in the 1990s. A sustainable system should be economically viable, socially and politically acceptable, environmentally benign, technologically adaptable, and institutionally manageable (Farshad and Zinck, 2001; Filson and Duke, 2004; Filson et al., 2003). The original focus on small farmers as target beneficiaries has been changed to address social inclusion, such as gender, cultural consideration and generational equity.

Second, the farming systems thinking evolved in terms of its focus on social processes of technological innovation. The first generation of FSR&E involved research into farming systems, the second as systems research into farming, and the third as critical farming systems (Bawden, 2002). As Bawden (2002) mentions, philosophical jargons equivalent to the three generations are respectively the hard systems appropriate for exploring strategies for technological change, soft systems appropriate for exploring human activities and critical systems aiming to address the power asymmetry and equity⁵.

The latest farming systems thinking urges integrating hard systems, soft systems and critical systems (Bawden, 2002). In generic terms, the focus on linkages and recycling between biophysical components at farming systems level, such as using crop residues as livestock feeds and composting crop fields by livestock manure, has evolved into linkages beyond biophysical components to include socio-economic parameters at various levels. However, integrating biophysical and socio-economic variables is complicated because the effective ways to investigate how some of these variables interact at different spatial and temporal scales are still emerging (Goss et al., 2004).

(b) Systems approaches to diffusion of innovation

The diffusion of agricultural innovation has long been perceived as a linear process: research as knowledge producers, extension as knowledge disseminators, and farmers as the passive recipients of the information being disseminated (Rogers, 2003). While FSR&E attempts to conceptualise technological innovation in systems perspectives, Agricultural Knowledge and Information System (AKIS) attempts to conceptualise diffusion of innovation from systems perspective. Information consists of a pattern imposed on data which simultaneously influences the interpretation of those data and enables them to be transmitted, while knowledge consists of a meaningful experience (Röling, 1990). Knowledge cannot be transmitted to others unless encoded or transformed into information. Knowledge generated in one component of the system is transformed into information for use in the other component of the system. Niels Röling (1990; 1994) proposed the AKIS and emphasised institutional pluralism for knowledge production, diffusion and application. His definition of the AKIS is as follows:

AKIS is a set of agricultural organizations and/or persons, and the links and interactions between them, engaged in such processes as the generation, transformation, transmission, storage, retrieval, integration, diffusion and utilization of knowledge and information, with the purpose of working synergistically

to support decision making, problem solving and innovation in a given country's agriculture or a domain thereof (Röling, 1990: 1).

While there are still apparent challenges to work with multiple stakeholders reconciling expert knowledge systems and local practices (Ammann, 2007; Pant and Hambly- Odame, forthcoming), the AKIS thinking lately embraces a holistic, cross-sectoral and multi-occupational nature of rural livelihoods with a revised focus on rural development and environmental management (FAO, 2000; Rivera, 2004; Röling and Jiggins, 1998). Furthermore, with the changing relationships between public and private actors, the revolution in information and communication technologies (ICTs), and new concepts of interactive learning and innovation provide new challenges to production, exchange and application to knowledge pertaining to agriculture and related activities (FAO, 2000; Hambly-Odame, 2003).

(c) Systems approaches to individual livelihoods

The small-farm focus of FSR&E thinking was reiterated by the holistic and people-centred approach of sustainable livelihood thinking because renewable natural resource-based activities are one of the important sources of livelihoods for small farmers in low-income countries (Chambers and Conway, 1992). The sustainable livelihood systems focus on assets, capabilities and activities required for a means of living (Brock, 1999; Cromwell, 1999; Niehof, 2004; Scoones, 1998)⁴. Sustainable livelihoods are, in fact, the emergent properties of soft systems as it recognizes how assets endowments are converted into capital entitlements (Bawden and Packam, 1989; Blaikie et al., 2002; Sen, 1999)⁵. The ability to convert asset endowments to resource and capital entitlements is influenced by a host of micro- and macro-economic contexts including policy, agreements, and conventions (Murray, 2001).

Depending on their ability to foresee vulnerability in the immediate future, three types of livelihood strategies are available for smallholder farmers in low-income countries (Brock, 1999). First, farmers either diversify or simplify agriculture depending on the agro-ecological comparative advantage. Second, if their livelihoods remain insecure from natural resource-based activities, both on-farm and off-farm, farmers expand into non-farming activities while staying on their own farm to increase income. Third, if they still fail to secure livelihoods, the last resort would be migration, which may be seasonal or even permanent. In a nutshell, farmers would generate livelihood outcomes, such as food security and well-being, through balanced use of on-farm, off-farm and non-farm livelihood strategies (Norman, 2002; Norman et al., 1995). Rural livelihood systems are increasingly characterized as cross-sectoral, multi-occupational and multi-locational, and thus the

new transition is from conventional focus on individual livelihoods towards community-based livelihood interventions (Ellis and Biggs, 2001).

In summary, although there has been a transition within each of the above systems' approaches, the set of conceptual tools provided by each paradigm have been inadequate in addressing key problems in low-income countries – economic downturn, climate change, environmental pollution, poverty, hunger and social exclusion – that transcend disciplinary, sectoral, institutional and hierarchical mandates. It would be appropriate to transform these systems approaches to developing an entirely new set of conceptual tools to address the increasing complexity in agriculture, renewable resource management and rural development. The new source of core competence lies on our ability to learn and innovate in response to changing technological, economic, social, climatic, and environmental challenges and opportunities.

TRANSFORMATION TOWARDS THE INNOVATION SYSTEMS APPROACH

Innovation systems in agriculture evolved within two distinct scholarly traditions: (1) innovation in manufacturing sector; and (2) innovation in renewable natural resource sector.

(a) The Industrial Revolution and subsequent emergence of innovation system thinking

Although innovation systems thinking is relatively new, the concept of innovation is centuries old. Francis Bacon's essay on 'The New Atlantis', published posthumously in 1626, is argued to be the very first text to examine the processes of innovation (Wallance, 1982). The early Industrial Revolution in Western Europe was foreseen by Bacon almost a century earlier (Bacon, 1901)⁶. It was also speculated upon by Adam Smith in 'The Wealth of Nations' (1776), of course, under the influence of Bacon (Smith, 1978). However, the mid-20th century theorists were still preoccupied by the technology transfer paradigm largely due to the massive economic, political, and socio-cultural changes brought about by the Industrial Revolution and its precedents of capitalist expansion and imperialism in Latin America, Asia and Africa (Wallerstein, 1979). One of the first attempts to investigate the changes brought about by the Industrial Revolution from systems perspective was the work of the Science and Technology Policy Research (SPRU) at The Freeman Centre, University of Sussex, U.K. (e.g. Freeman, 1987; Patel and Pavitt, 1997, Pavitt, 1999).

The innovation systems thinking is also linked to Staffan Linder, a liberal economist and a former conservative minister in the Swedish Government (Lundvall et al., 2002). Linder (1961)'s essay on 'Trade and Transformation' inspired Bengt-Åke Lundvall, and his colleagues at Aalborg University,

Denmark to work on innovation systems thinking. A definition of innovation system is as follows:

The narrow definition would include organizations and institutions involved in searching and exploring – such as R&D departments, technological institutes and universities. The broad definition...includes all parts and aspects of the economic structure and the institutional set-up affecting learning as well as searching and exploring – the production system, the marketing system and the system of finance present themselves as sub-systems in which learning takes place (Lundvall, 1992b: 12).

The World Bank (2007:xiv) defines an innovation system ‘...as a network of organizations, enterprises and individuals focused on bringing new products, new processes, and new forms of organization into social and economic use, together with the institutions and policies that affect their behaviour and performance.’ In essence, an innovation system is the network of public and private actors engaged in production, exchange, regulation and application of knowledge in a particular domain of economic activity. The application of knowledge and technology to create new products, new processes, and new organisational forms requires a range of support services, such as credit, inputs, insurance schemes and social safety nets that are well beyond the scope of research systems. Thus nation states are responsible for providing favourable public policy environments for advancements of science, technology and innovation for development.

Lundvall et al., (2002) assert that as long as nation states exist as political entities with their own agendas to innovate, it is useful to work with the concept of national systems. This notion is analogous to that which Friedrich List (1841) argued about national systems of production in his best known work ‘The National System of Political Economy.’ Lundvall et al., (2002) further argues that regionalisation and globalisation of the economy definitely weakens national capacity to innovate, especially when the knowledge exchanges are tacit and difficult to codify, such as local and indigenous ways of learning and innovation. Stakeholders who originate from different cultures, such as scientists trained through formal schooling and local and indigenous communities, may have a hard time engaging in interactive learning and innovation (Lundvall et al., 2002). Hence, there may be tension between pan-regional and global integration of expert knowledge systems through patenting and licensing, and appreciation of diversity in local and indigenous knowledge and practices at the national and sub-regional levels (Sumberg, 2005).

Finally, the arguments for qualifying innovation systems thinking turn out to be pragmatic in the realm of public policy. On the one hand, although

nation states are responsible for national public policies, this does not preclude the importance of regional and global policies. Indeed, the process of regionalisation and globalisation of innovation makes it even more pertinent to understand the role of nation states (Freeman, 1987; Lundvall, 1992b). Therefore, nation states are the basic unit of analysis for addressing complexity of regional and global systems. On the other hand, nation states vary at national as well as sub-regional levels. Focus on national, pan-regional and international levels overlook the socio-economic impacts of interventions at the local level. However, given the proximity of firms or farms in a local cluster or virtual networks, innovation would occur whether they compete or complement each other (Burger et al., 2001).

(b) Sectoral transformation towards the innovation systems in agriculture

After the advent the 21st century, humanity not only inherited the challenges from the previous centuries, such as negative environmental, social and political impacts of the Industrial Revolution but also new challenges emerged and opportunities opened due to global changes in climate, environment, technology, politics, economies and increasingly greater interdependence of nation states. One approach to address the challenges and opportunities in low-income countries has been the innovation systems approach in renewable natural resources and agriculture because it is realised that symmetric economic growth in countries where people are overwhelmingly dependent on renewable natural resource-based livelihoods would come through investment in agriculture (World Bank, 2008; IAASTD, 2008).

An application of the innovation systems thinking in agriculture implies transition through the innovation systems framework from one sector to another. However, the research and extension systems in agriculture requires a transformation – a ‘paradigm shift’ – because the set of tools provided by these systems, including various transitions through the farming systems, knowledge and information systems, and livelihood systems discussed above, have been inadequate to address the challenges of the 21st century. Nevertheless in the context of the origin of the innovation systems concept, four major limitations are apparent in applying the innovation systems framework in agriculture in low-income countries. Firstly, the focus should be on systems building in addition to its application on systems analysis because in most developing countries innovation systems do not exist (Lundvall et al., 2002). Despite considerable investment in agriculture this limitation is still apparent in agriculture because the initial efforts were focused on diagnostic studies to demonstrate relevance of innovation systems approach in agriculture (Rajalahti et al., 2008; Ekboir and Hambly-Odame, 2007). Secondly, the systems building processes should systemically recognise the innovative

capacity and epistemological backgrounds of all relevant stakeholders, including socially excluded women, youth, small-scale producers and resource-poor farmers (Shiva, 1997; Stamp, 1989). Such concerns specifically relate to the question of power and the influence of power structure on various ways of learning and innovation (Lundvall et al., 2002).

Thirdly, it is important to develop processes to facilitate stakeholder interaction involving the public and non-profit private sectors, on the one hand, and the for-profit private and informal sectors, on the other, because the innovation systems framework has evolved from manufacturing where actors are predominantly from the corporate sector (Edquist, 1997; Lundvall, 1992a; Nelson, 1993). Thus public-private partnerships should also involve informal sector stakeholders, including local and tribal communities. Finally, unlike the case of manufacturing, agricultural production cycles are longer and influenced by technological, biophysical, cultural, political and socio-economic factors. There is an apparent challenge to address the generic differences between firms and farms, specifically when agriculture is primarily practised for subsistence in resource constrained contexts (Clark et al., 2003).

In short, conceptually rural development and agriculture traversed two major paradigm shifts – first, from the technology transfer to the research and extension systems, and then to innovation systems. These paradigm shifts brought about parallel changes in organisational and institutional arrangements, and provide new challenges to managing economic, social and environmental changes in global agriculture.

INNOVATION PROCESSES IN AGRICULTURE

The first paradigm shift from technology transfer to research and extension systems has reflected systemic reforms in policy and practices, such as a move from the training and visit (T&V) systems of extension to more inclusive programmes such as on-farm trials and farmers field schools (FFSs) integrating expert knowledge-based learning and experimentation with local knowledge and practices. However, these reforms were more of *science and technology (S&T) policy* changes in agriculture. The second paradigm shift towards the innovation systems calls for reforms in *innovation policy*, including changes in *S&T* policy.

INNOVATION IN RESEARCH AND EXTENSION SYSTEMS

In the past, the technology transfer paradigm influenced policies enabling delivery of technological messages to rural farming communities. Research, extension and educational organisations were established to facilitate

agricultural research and extension, often with a focus on commodity programmes by major crops, such as research and extension in rice, wheat and maize. Government agencies were committed to facilitating farmers' access to land, farm machinery, high yielding crop varieties, fertilizers, pesticides, irrigation and credit. In South Asia, for example, the T&V system was promoted until the 1990s (Sulaiman and Hall, 2002). The T&V system institutionalised regular monthly workshops involving research scientists and extension officers. The extension officers in turn conducted fortnightly training for village level extension workers. From regular trainings and occasional farm visits, extension officers used to bring back first-hand experience of rural farming situations. This linear approach assumes that fundamental research is the source of innovation, and formally organised public extension systems and mass media pass it to farming communities, often ignoring local and indigenous knowledge and practices (Mundy and Compton, 1995).

When negative impacts of the *Green Revolution* technologies were apparent, practitioners and theorists questioned the linear paradigm of agricultural research and extension, leading towards the emergence of various systems approaches with various degrees of integration of expert knowledge-based interventions, and local and indigenous knowledge and practices. Under the influence of the FSR&E approach, researchers introduced the practice of on-farm trials. Researchers employ various levels of on-farm trials based on the stakeholder involvement at planning and implementation stages (Norman et al., 1995). First, trials are moved to farmers' fields, but these are planned and implemented by researchers, and known as *researcher planned and implemented trials*. Usually there are rental contracts between researchers and farmers to use designated pieces of land.

The second type of on-farm trial is *researcher planned and farmer implemented*. In this case, farmers are the passive recipients of the researchers' ideas to be tested. They still participate as hired labours. A third type of trials is *farmer planned and implemented*, where farmers have a greater role in decision making. As we move along this continuum of the typology of trials, there is increasing participation of farmers in decision making and relatively greater opportunity to integrate expert and local ways of learning and experimentation. However, most of the on-farm trials are limited to farmers' participation for material incentive as they participate by providing resources, such as land and labour in return for food, cash and other material incentives (Pretty, 1993). The objectives of on-farm trials are to demonstrate the benefits of modern technology, such as yield potential of modern crop varieties over traditional varieties, and persuade farmers to adopt modern technologies. In reality, however, local and indigenous technologies, such as local crop varieties, often perform better than modern ones, particularly under farmers' management practices, and in absence of

external inputs, such as chemical fertilizers and pesticides (Biggs, 1983). Recognising this flaw of expert knowledge-based learning and experimentation, local crop varieties and associated knowledge were integrated in the formal research systems as early as the mid-1990s (Fujisaka, 1995). However, small changes without a transformation across the research and extension systems had very limited development impact.

A revised focus on farmers' participation in agricultural research and extension has been achieved through farmers' field schools, a kind of 'discovery learning' through collaboration of extension workers and farmers in key areas such as pest management, nutrient management, water management and crop improvement. Farmers' participation in such processes has become relatively more functional because they participate by forming groups with their specific interest in discovery learning and problem solving (Pretty, 1993). Contrary to individual learning in the technology transfer approach, systems approaches encourage social learning through interaction among stakeholders, integrating expert knowledge-based learning and innovation with local and indigenous ways of learning and innovation (Leeuwis, 2004). As far as social learning is concerned, crop improvement, for example, typically involves four stages – selection of source germplasm, trait development, cultivar development and varietal testing (Morris and Bellon, 2004). A complete participatory plant breeding (PPB) involves farmers at all stages while efficient PPB involves farmers at germplasm selection and varietal evaluation. At the extremes of the continuum, researchers either work independently from farmers at all stages as was common in the transfer of technology approaches or farmers save their own seeds, often through mass selection based on physical appearance, and local knowledge and perception, irrespective of the scientific research and development (R&D) (Ceccarelli et al., 2000; Humphries et al., 2005; Morris and Bellon, 2004).

INNOVATION IN INNOVATION SYSTEMS

A range of case studies that employed innovation systems thinking revealed that farmers' participation in the research process is necessary but not sufficient for production, exchange and application of knowledge held among myriad of stakeholders (Table 2). Review of the case studies clearly resulted in two broad categories of the innovation systems study in agriculture: (1) technology-specific studies; and (2) commodity-specific studies. The first category of inquiry begins with the development of *process technology*, such as agricultural biotechnology and PPB. Processes technology oriented studies focused on farmers' participation in research and technology development often with an intermediary role of non-governmental organisations (NGOs) (Clark et al., 2002; Joshi et al., 2005). The role of the for-profit private sector

was relatively informal. In Andhra Pradesh India, conventional biotechnology, such as tissue culture, bio-fertilizer and bio-pesticides, were promoted in the short-term while the long-term strategy had been on molecular biotechnology and genetic engineering. In the Chitwan district of Nepal, participatory plant breeding (PPB) had been promoted and efforts were made to reduce the dichotomy between participatory and centralised plant breeding practices, often subjecting PPB varieties and farmers varieties into centralised varietal testing procedures, such as on station disease screening and multi-location testing (Pant and Hambly-Odame, forthcoming). In this effort, PPB has been redefined as client-oriented breeding depending on the involvement of local and indigenous communities (Witcombe et al., 2006; Witcombe et al., 2005).

Table 2 Case studies on innovation in innovation systems

Process technology
1. Agricultural biotechnology led by public university in India under the support of the Dutch Ministry of Foreign Affairs (Clark et al., 2002). 2. Participatory rice improvement led by civil society organisations in Nepal under the support of the UK Department for International Development (Joshi et al. 2005).
Commodity production for domestic uses
1. Small-scale food processing led by civil society organisations in Bangladesh without external support (World Bank, 2007). 2. Tomato production and post-harvest led by civil society organisations in India under the support of the UK Department for International Development (Clark et al., 2003). 3. Potato production and post-harvest led by the government agencies and civil society organisations in Peru under the support of the Swiss Agency for Development and Cooperation (SDC) (Devaux et al., 2007).
Commodity production for export markets
1. Vanilla production and post-harvest led by farmers' cooperatives in India without external support (World Bank, 2007). 2. Pineapple production and post-harvest led by the government agencies in Ghana under the support of the German Agency for Technical Cooperation, the U.S. Agency for International Development and the Natural Resources Institute, UK (World Bank, 2007). 3. Cut flowers production and post-harvest led by a farmers' association in Columbia without external support (World Bank, 2007). 4. Floriculture led by the government agencies and civil society organisations in Kenya under the support of international research organizations, such as International Centre of Insect Physiology and Ecology (ICIPE) and CABI (Bolo, 2007).
Commodity production for both domestic and export markets
1. Mango production and post-harvest led by the government agencies in India under the support of the UK Department for International Development (Hall et al., 2003a). 2. Medicinal plant and Ayurvedic medicine led by civil society organisations and private companies in India without external support (World Bank, 2007). 3. Cassava production and processing led by government agencies and civil society organisations in Columbia without external support (World Bank, 2007). 4. Cassava production and processing led by government agencies in Ghana without external support (World Bank, 2007). 5. Shrimp production and post-harvest led by civil society organisations in Bangladesh without external support (World Bank, 2007).

The second and most common category of study of innovation systems in agriculture begins with a focus on *commodity production and post-harvest processing*, either for domestic uses, export markets or both. Production and post-harvest management of tomato in India and potato in Peru illustrate how NGOs and farmers' organisations facilitate innovation systems when small-holder crop producer in niche specific agro-ecological conditions target domestic markets. Tomatoes from the foothills of the Himalayas (Clark et al., 2003), and potatoes from the Andes (Devaux et al., 2007) carry brand names that are recognised in the domestic markets in respective countries. The diversity of Peruvian potato cultivars facilitates pro-poor innovation systems to function because diversity does not work with monoculture and agricultural mechanisation preferred by large-scale producers. In these cases, NGOs facilitate sector coordination often with a challenging task of involving stakeholders from the for-profit private sector.

Crop production for export markets has more challenges than production for domestic market or household consumption. Anticipating new produce demands under changing consumer preference in a distant market, increasingly stringent regulations, and price competition from other countries are a few typical challenges. For example, Indian vanilla could not compete with artificial vanilla in the international market; Ghanaian pineapple growers switched to new varieties and involved themselves in value-added products including cut and sliced fruits and certification for fair trade and organic produce; Colombian cut flower producers shifted from carnations and chrysanthemums to spray carnations and roses, and from stems to ready-made bouquets (World Bank, 2007); and Kenyan flower exporters experimented with sea shipment protocols and market diversification of cut-flowers to increase price competitiveness (Bolo, 2007).

In India, interaction between major actors, such as vanilla farmers, public research and support agencies and private companies was missing. In Ghana, the success of farmers' owned export companies established by the government was limited although the government supports non-traditional exports, such as through a free trade zone establishing certification mechanisms with specific training on pesticide management. In both Colombia and Kenya, the success of the floriculture sector was limited by physical and emotional distance between the flower sector and research community leading to weaker interaction of expert knowledge-based interventions, and local and indigenous practices leading to over reliance on international R&D for which farmers have to pay costly fees and royalties.

Targeting production and processing for the domestic as well as the export market creates an additional challenge of bringing small-scale and large-scale entrepreneurs together. Crop production and post-harvest for domestic uses has to compete with the large-scale production and processing

for export as lower quality produce that are not suitable for export remains in the domestic market. For example the small-scale food processing in Bangladesh experienced competition from large-scale food processors which affected the livelihoods of poor food processors, mainly women (World Bank, 2007). The specific challenges of small-scale food processors include: (1) insufficient technical skills to meet hygiene standards and consumer preferences; (2) credit markets and tax incentives deliberately designed for large-scale processors, and (3) the physical and emotional isolation from urban centres. Specifically the food sector coordination was hindered by physical and social isolation of small-scale food processors from urban consumers, service providers, and large-scale processors in spite of supportive interventions from non-governmental organisations NGOs.

In the Indian mango sector, an unsuccessful attempt was made to address the divides between small-scale producers and large-scale producers through the establishment of farmers' cooperative federation and their collaboration with other stakeholders for sea freight of mangoes to London U.K. (Hall et al., 2003a). Initially perceived to be a technical problem, the unacceptable quality of mangoes arriving in London was realised, only after three years, as the missing links between pre-harvest and post-harvest service agencies to effectively manage anthracnose, a quality-related disease. In a similar case, a small number of large pharmaceutical companies in India developed associated research, design, and marketing organisations in herbal medicine with strong links to the international market to increase their market share (World Bank, 2007). However local health practitioners and rural communities holding the ethno-botanical knowledge and practices under the philosophy of Ayurveda were marginalised. Not only did the Medicinal Plant Board of India failed to promote effective sector coordination but also non-profit private sector actors, such as NGOs and private foundations, were unsuccessful in coordinating traditional health care workers and rural development workers towards integrating expert knowledge-based herbal medicine, and local and indigenous practices of health care. The sector coordination was hindered by a long-established mistrust among public research organisations, the private sector and NGOs, coupled with philosophical differences between scientific and traditional medicine, and the resistance to integration and interaction of multiple stakeholders.

Cassava processing in Colombia and Ghana, to produce animal feed and starch, also provided lessons on how one should deal with the divide between small-scale and large-scale producers. The relative success of the sector in Colombia relied on stakeholders' willingness to explore different forms of partnerships and long-established traditions of cooperative movement and industry associations (World Bank, 2007). However, the focus on research *per se* was rarely extending linkages beyond the research system. Likewise,

in Ghana, the Ayensu Starch Company Limited (ASCo) provided infrastructure and incentives to the private sector, facilitated interaction between actors, and coordinated and supported a network of small-scale cassava producers (World Bank, 2007). The interaction was, however, classically top-down and therefore could not facilitate effective knowledge sharing.

In addition to the duality between small-scale and large-scale producers, the Bangladeshi shrimp industry was required to comply with increasingly stringent markets, such as the US Food and Drug Administration's Hazard Analysis Critical Control Point (HACCP) sea food regulation, address environmental protection and social equity considerations associated with shrimp production (World Bank, 2007). NGOs provided technical support to poor shrimp farmers but they were inefficient in linking shrimp farmers with the research systems, markets and domestic policy process.

The above case studies revealed that success of an agricultural intervention lies on actor structure facilitating the interaction of resources (natural, financial, human, social and human made capitals), knowledge management processes including integration of expert knowledge systems, and local and indigenous knowledge and practices, and stakeholder values around economic growth, social inclusion and environmental protection (Christensen et al., 2004, Pant, forthcoming). In other words, a key challenge for learning and innovation was fostering broad-based sector coordination beyond the conventional boundaries of the public, non-profit private, for-profit private and informal sectors. One of such challenges is bridging the socio-psychological divide between scientific research, and local and indigenous practices (Pant and Hambly-Odame, forthcoming). Value systems of stakeholders, individual as well as collective, are influenced by how public and private stakeholders behave within an organisation and across the innovation system (Durham, 1991). A deviation from the long-established value systems and organisational culture pushing the conventional boundaries, of course for positive changes across innovation systems, would provide leverage to sector coordination (Casson, 2003; Pant and Hambly-Odame, forthcoming; Sternin and Choo, 2000; Williams, 2002).

TOWARDS A NEW GENERATION OF INNOVATION SYSTEMS RESEARCH

In the retrospect, the mid-20th century *Green Revolution* in developing countries brought a many-fold increase in productivity of rice, wheat and maize. This success resulted through international collaboration and government commitments to farmers' access to land, farm machinery, high yielding crop varieties, fertilizers, pesticides, irrigation and credit (Conway, 1997; Parayil, 1992). However, in general poor farmers in arid and marginal

areas who were already vulnerable hardly realised any benefits, notably the African continent was largely bypassed. Moreover, the *Green Revolution* caused some negative environmental impacts, such as soil degradation, air and water pollution, and loss of biodiversity and associated knowledge and practices. Biodiversity loss is a kind of memory loss because local and indigenous knowledge get lost with it (Nazarea, 1998). The negative social and environmental impacts were the unintended consequences of well-meaning interventions to feed starving people in low-income countries, for example, the Bengal Famine in India (1942-1943) with four million deaths in 1943 alone (Axinn, 1988; Singh, 1999). In response to these negative social and environmental repercussions, sustainable agricultural practices, such as multiple cropping, biodiversity conservation and low-external input agriculture, were promoted as early as 1970s under the rubric of FSR&E (Pretty, 1993).

In addition to the mid-20th century challenges that are still being unsuccessfully addressed under the paradigm of research and extension systems, new sets of *actors* and *factors* are emerging in the 21st century, posing seemingly intractable challenges to achieve global prosperity. Private corporations (PCs) and NGOs are becoming increasingly active often challenging the *status quo* of the public sector. For example, PCs in life sciences are at the forefront of modern agricultural science and technology, specifically biotechnology and genetic engineering, often referred to as the *Gene Revolution* (Parayil, 2003). Biotechnology and genetic engineering have a huge potential to breed stress tolerant, disease resistant, and nutrient fortified crop varieties, and disease tolerant animal breeds, but today's investments in biotechnology, concentrated in the private sector and driven by commercial interests, have had limited impacts on smallholder productivity, specifically in low-income countries because the research systems are further detached from the local and indigenous knowledge and practices (World Bank, 2008). Activist NGOs are influencing government to enact stringent legislations in agriculture to advance positive social and environmental changes, but stringent environmental legislations are not free from unintended consequence, such as a reduction in agricultural productivity.

Along with socio-economic factors, climatic and environmental *factors* are rapidly changing. Climate change, for example, has increasingly affected, and has been affected by, agriculture as a result of a *positive feedback* cycle of carbon emitting industrial agricultural practices further amplifying climate change (IPCC, 2007). Sustainable agricultural practices, such as agro-forestry, home gardens, perennial crops and minimum tillage, are either carbon sequestering or carbon neutral, thus stabilising greenhouse gas emission through a *negative feedback cycle*. Moreover, environmental pollution and natural resource degradation as a result of unsustainable

agricultural practices not only jeopardizes human health and ecological integrity putting more pressures on healthcare systems, but also reduces agricultural productivity, thus limiting the supply of safe and adequate foods (IAASTD, 2008). Thus one of the intractable challenges of the 21st century is to increase agricultural productivity while ensuring ecological integrity and human well-being. One way to address this challenge is to explore complementarities between *science and technology policy*, and *environmental policy* (OECD, 2005). Specifically in international development, *social policy* is equally important. However, the motivations for these policy portfolios are different: *S&T policy* is traditionally driven by productivity and national competitiveness; *environmental policy* is driven by international agreements and concerns for our planet; and *social policy* is motivated by welfare or equity goals, such as providing social safety nets to vulnerable sections of society until their adaptation capacity is sufficiently developed. However, such an adaptation capacity cannot be developed through replacement of local and indigenous adaptation practices but through an integration of expert knowledge-based adaptation strategies with that of local and indigenous communities (Bhattacharyya, 2006).

Global change literature, specifically in climate and environmental change, has moved beyond its conventional focus on assessing change and determining ecological and human vulnerability, and begun a scholarship of developing local *adaptation capacity*, a convergence with the literature in rural and international development (Adger, 2006; Gallopin, 2006; McLaughlin and Dietz, 2008; Smit and Wandel, 2006). However, specifically in renewable natural resource management and agriculture, the conventional tools provided by the research and extension paradigms of innovation, including various transition throughout the last decades, have consistently failed to address the challenges and opportunities created by rapidly changing actor and factor structures.

Since the tools provided by research and extension systems were inadequate to address the challenges of the 21st century in low-income countries, it is imperative to transform the research and extension paradigms into innovation systems paradigm, moving beyond the conventional focus on research systems, and also facilitating learning and innovation to respond to rapidly changing contexts (World Bank, 2007; Rajalahti et al., 2008; Rajalahti, 2009). The new generation of research on innovation systems, therefore, should move beyond technology-specific as well as commodity-based interventions as are evident from the case studies on innovation in innovation systems. In addition to these two types of interventions, a third category of potential interventions would focus on consumer concerns, such as carbon neutral and/or carbon sequestering agriculture, low-external inputs agriculture, advancements of smallholder agriculture, sustainable use

of forest products and medicinal herbs, and fair trade practices (Carlsson et al., 2002). These interventions are neither within a domain of a particular disciplinary research and extension systems nor under a mandate of a commodity programme, and thus the contemporary challenge is to develop a new generation of innovation systems research that investigates the convergence of three, seemingly distinct, fields of interdisciplinary studies: *environmental management*, *international development* and *innovation studies*.

One way forward to achieve the convergence is to focus on innovation capacity development in renewable natural resource management and sustainable agriculture while addressing the seemingly intractable social problems, such as food crisis, hunger and social exclusion. Building the *capacity to adapt*, also referred to as *capacity to innovate* within a broader framework of innovation systems, entails the development of collective context-specific skills, practices, routines, institutions, and policies to put existing and new knowledge, including local and indigenous knowledge, into productive use in response to changing technological, economic, social, climatic, and environmental challenges and opportunities (Hall, 2005). The capacity to innovate is an emergent property of a system that comes through the interrelationships and interactions among various elements of the system (Morgan, 2005). In practice, the thinking on capacity development and innovation systems intersects on two critical points – fostering sector coordination, and facilitating interactive learning and innovation (Hambly-Odame et al., 2007; Pant and Hambly-Odame, 2006).

CONCLUSIONS

Clearly, there have been two major paradigm shifts in agricultural science, technology, innovation and development. The first paradigm shift was from technology transfer to various research and extension systems, and the second was from research and extension systems to innovation systems. Although systems research had been introduced in agriculture as early as the mid-20th century, public sector predominance in research and extension is still evident in many low-income countries. New ways of managing rural prosperity have been increasingly sought in response to the development of new technologies, such as transgenic agriculture, agro-energy production, and ICTs, and emergence of new actors including non-profit private organisations, private foundations and private companies. The new ways of managing rural prosperity involve not only the scientific research and technological innovations, but also how stakeholders learn in response to seemingly unknown and uncertain economic, social, climatic and environmental changes.

The available case studies on the analysis of the innovation systems in agriculture demonstrated that the collaboration of stakeholders with apparently conflicting value systems is the greatest hindrance to building innovation systems. In other words, the greatest challenge in managing global prosperity involves collaboration among stakeholders with seemingly conflicting goals, such as enhancing economic growth, maximising social welfare and equity, and minimising environmental damage. When stakeholders are required to work at the interface of environmental management, international development, and innovation studies, the challenge to address the paradox of productivity and sustainability would be formidable unless the issue of social equity at the bottom of the pyramid is addressed. An innovation systems approach that integrates management, development and innovation is critical for better policy outcomes and learning. Therefore, we need the innovation systems mode of framing agriculture and natural resource interventions.

NOTES

- 1 The authors would like to acknowledge the International Development Research Centre (IDRC) of Canada for funding this work.
- 2 The authors appreciate that a fair treatment of these well-established systems approaches demands a book length, but the aim in this paper is to provide a context to the evolution of the innovation systems in agriculture.
- 3 Theorists characterise systems thinking in terms of the processes of inquiry: hard systems recognise the world as systemic while soft systems view the processes of inquiry as systematic (Bawden, 2002; Checkland, 2000).
- 4 *Asset* is that which one has while *resource* is that which one uses (Niehof, 2004). When resources are used to create new resources, they are called *capital*.
- 5 Emergent properties are the properties visible only at the systems levels.
- 6 The changes during the *Industrial Revolution* speculated by Bacon and reiterated by Smith included disciplinary education, the establishment of specialized laboratories, and improvements in techniques of measurement and experimentation to increase the cognitive efficiency of discovery, invention and innovation.

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Low-income Countries and Innovation Studies

A Review of Recent Literature

Jo Lorentzen

SUMMARY

This is a review of the literature on innovation in the world's poorest (or low-income) countries (LICs), published between 1997 and 2008. It asks what role innovation plays in the LICs, and how much and what exactly we know about it. It shows that traditional innovation studies, in particular, has rather neglected the LICs. Most research addresses problems concerning agriculture and health and focuses not on firms but on individuals, households, and communities as principal units of analysis. The literature is rather fragmented and there is no evidence of a systematic research agenda concerning innovation of and for the Bottom Billion. However, there are a few incipient themes -- such as learning, community participation in development projects (a concept close to user-driven innovation), or innovation diffusion versus technology transfer -- around which a LICs-focused research programme could emerge.

INTRODUCTION

It is almost tautological that the knowledge economy requires investments in science, technology, and innovation (STI). To the extent that they bear fruit, they help leading economies to push the frontier, advanced developing economies to catch up, and poor countries to escape development traps. STI has become an essential part of success stories in the developing world, regardless of whether they are relayed by academics, policymakers, practitioners, or entrepreneurs, and whether the stories are about activities in the primary, secondary, or tertiary sector. In fact, in 2000 the United Nations underlined the importance of STI for the achievement of the Millennium Development Goals (MDG), and thus for getting the majority of humanity out of poverty (UN Millennium Project, 2005).

Such a consensus is relatively new. Although in some developing countries investments in science – but less so in technology and innovation – were part and parcel of policymaking post-independence, STI was generally seen less as a means to and more as an end of development. In fact, for the better part of the past century, innovation was mainly perceived to be the privilege of rich countries. Its benefits would become available to the developing world in the form of technology, and only once the technology was comprehensively mastered would it make sense for poor countries to try and grapple with the science behind it. Up to that point, it was simply more efficient to adopt, and possibly adapt, external knowledge. However when growth became more knowledge-intensive and globalisation ensured that even hitherto relatively protected corners of the planet were exposed to competition, the idea of STI as a means to development grew stronger and publications that somehow linked ‘knowledge’ to ‘development’ proliferated (e.g., Bernardes and Albuquerque, 2003; World Bank, 2006).

For example, the investment climate surveys of the World Bank which cover 123 countries routinely ask respondents about their investments in product or process innovation. A number of developing and transition economies, including the BRICS countries, have adopted the innovation surveys of the OECD and the European Union. The African Union (AU), having made (but not much honoured) commitments to increase resources for R&D, even plans such a survey for the entire continent (see the special issue of the *African Statistical Journal* 6 (May); Bamiro, 2006). Thus, in a normative sense at least, STI matters.

However what role does it really play? The question behind the literature review undertaken in this paper is how much and what exactly we know about innovation in very poor countries, namely those that the UN classifies as low-income countries (LICs), and whose inhabitants are sometimes referred to as the Bottom Billion (Collier, 2007). A recent and very comprehensive review of the evolution of science policy and innovation studies produced no evidence that LICs ever enjoyed much attention in the field (Martin, 2008), including since the mid-1990 or so by which time ‘(national) innovation systems’ had become a household name in the policy world and published research on innovation started growing at a much higher rate than in the previous three decades (Fagerberg, 2005: Figure 1.1). What is known is that measures of national technological and social capabilities which underlie realised or incipient innovative potential are highly correlated with development (Fagerberg, Srholec and Verspagen, 2009) and that this holds across low-, medium-, and high-income countries (Fagerberg and Srholec, 2008).

Hence if STI is crucial to the development of very poor countries, one would expect that research into its determinants and impacts is plentiful.

This is not the equivalent of catch-up optimism whereby the convergence of growth rates is somehow automatic and thus inevitable (cf. Verspagen, 1991). Since the developmental deficits and needs of low-income countries are evidently of a different order of magnitude from those of other developing countries, constraints on STI must be even better understood than elsewhere so that they can be appropriately addressed; and that STI's much vaunted power of transformation can in fact be harnessed. In other words, no one needs research on STI more than the Bottom Billion.¹ One would further expect that it covers most if not all LICs and that it brings concepts from innovation studies to throw light on relevant issues in LICs.

Prior to the recent revival of discussions of STI in the context of the knowledge economy and developing countries, there have been various attempts to explain why innovation had proved largely elusive in the developing world. A review of the pertinent literature up to the mid-1970s mentioned the absence of linkages between government, industry and education, and the widespread irrelevance of public-sector research for either industry or the problems of their countries at large; the absence of high-level coordination of scientific activities; the lack of demand for innovation by an industrial sector entrenched in sub-optimal equilibria and monopolistic markets with no incentive for upgrading; the dominance of multinational enterprises which controlled unsalable technological assets against small or medium-sized local firms with very circumscribed capabilities and the effects this may have on competition; and the nascence of assembly industries geared to exports which assigned subordinate roles to local producers. In sum, problems existed with respect to demand for and supply and coordination of STI activities (Crane, 1977).

Others detailed the decline in investments in research and concluded that there was simply not enough critical mass of activity to yield any outcomes (Lipton, 1988; Pardey et al., 1997) and criticised the discrepancy between policy commitments and incentives (Lorentzen, 2010). Especially for Africa, there is no shortage of rather downbeat assessments (e.g. Lall and Pietrobelli, 2002), mirrored by widespread frustration in Latin America that STI had never much lived up to its productive promise (Correa, 1995). Meanwhile, attention in Asia focused more on the evident success stories of first- and second-generation tiger economies than on low-income economies in South Asia (e.g., Amsden, 1989; Kim, 1997; Wade, 1990). To this day, when authors refer to 'developing countries' (Da Silveira, 2001), 'technology-followers' (Forbes and Wield, 2000), or 'economic development' in the context of innovation systems (Niosi, 2008), they normally have more advanced developing countries at the cusp of catch-up in mind. Even seminal reviews of technological learning in least developed countries rely by necessity more on insights from middle-income countries than on research undertaken in LICs themselves.²

A new take on an old argument is that even in the face of an increasing share both of global R&D and national income generated in low-income countries, innovation capacity has lagged because the attendant technology development was often oriented to first-world needs and thus inappropriate (Kaplinsky et al., 2010). This reasoning can be exaggerated, especially if undertaken at the expense of, rather than complementary to analyses showing that underfunded systems cannot be expected to produce great results.

What is not controversial is that the conditions under which innovation takes place – or not, as the case may be – differ fundamentally between advanced and very poor countries. At issue is ‘relative scarcity’ (Srinivas and Sutz, 2008), namely missing or outdated infrastructure, inadequate access to requisite materials and equipment, lack of institutional support for building capabilities and of appropriately skilled human capital, and of resources. Cognition and problem-solving – short of giving up – need to adapt to such conditions. This means that learning has characteristics different from those found in advanced countries where the availability of inputs is less of an issue. Although by definition no environment is without (incidental) scarcity, only developing countries face systemic scarcity. In the extreme, scarcity can obviously prevent innovation and development, but can also induce innovations, even though they may end up being intensely local and thus not scale up particularly well. As such, they may also remain hidden from view which is one reason why there may be less literature on innovation in LICs than desirable, and why much of it might be country-specific or otherwise idiosyncratic, rather than producing more general insights (*ibid.*).

The article proceeds as follows: The next section summarises the methodology of the literature review. Then it describes a few highlights of the results such as when this literature first started to appear in the recent past, who produced it, and which countries and issues were covered. Following that the review gives an in-depth view on more analytical issues that are at the core of innovation studies, namely the types of innovation, the origins of technology transfer, the nature and scope of networks and institutions, and so on. The concluding section discusses consequences for emerging research on innovation in low-income countries.

METHODOLOGY

The review is based on a search performed using ISI-Web of Knowledge for the 12-year period from January 1997 to December 2008. The key search term was ‘innovation’ but since not all disciplines employ this terminology, ‘development’ was also included. The two search terms were individually paired with groups of countries and individual LICs. The key target group

was low-income countries, yet in order to ensure that LICs referred to less precisely as ‘developing countries’ or not equivalently but with some degree of overlap as ‘least developed countries’ (LDCs), these were also included as search terms. Since only about a third of all developing countries are also LICs, the search was bound to result in hits that were discarded in the analysis. Table 1 shows the results of the search.

Table 1 Results of the Keyword Search

Keyword combinations	Hits
1. Developing countries AND innovation	474
2. Low-income countries (or LICs) AND innovation	33
3. Low-income countries (or LICs) AND development	648
4. Least developed countries (or LDCs) AND innovation	12
5. Least developed countries (or LDCs) AND development	273
6. ‘Afghanistan’ ... ‘Zimbabwe’ AND innovation	351
Sum 1.-6.	1,798
7. ‘Afghanistan’ ... ‘Zimbabwe’ AND development	14,994
Total	16,793

Selection criteria for relevance included that the article in question had to address:

1. A product, process, or organisational innovation, or institutional factors relevant for innovation, such as intellectual property rights.
2. One or more LICs, including as a group.

From Searches 1-6 in Table 1, the author and two other researchers independently from one another first selected articles based on their abstracts and, if found relevant, then a group of seven researchers including the author proceeded to read and, if confirmed relevant, code the full text which was entered into an Access database. Coding included comprehensive bibliographic data as well as information about theory, research question, methodology, data, and unit and results of analysis. Where available, it drew further information about sectors covered, the types and origins of innovation, knowledge transmission mechanisms, the nature of networks, the scope of coverage, and policy orientation.

On this basis, 271 (15%) abstracts and 152 (8%) articles were identified as relevant. Table 2 shows that one out of four articles among the individual country searches was relevant, whereas in group searches this ranged from 0 (for LDCs AND development) to 9 per cent (for LICs AND innovation).³

Therefore most research on innovation in LICs is country-specific and there are only roughly half as many articles that address more than one LIC at once. Overall 6 per cent of articles in the group search that came up through ‘innovation’ turned out to be relevant which in relative terms is three to four times as many as for those that turned up through ‘development’. It is then possible to estimate the loss of information from not having undertaken Search 7 in Table 1 as some 200-300 articles.

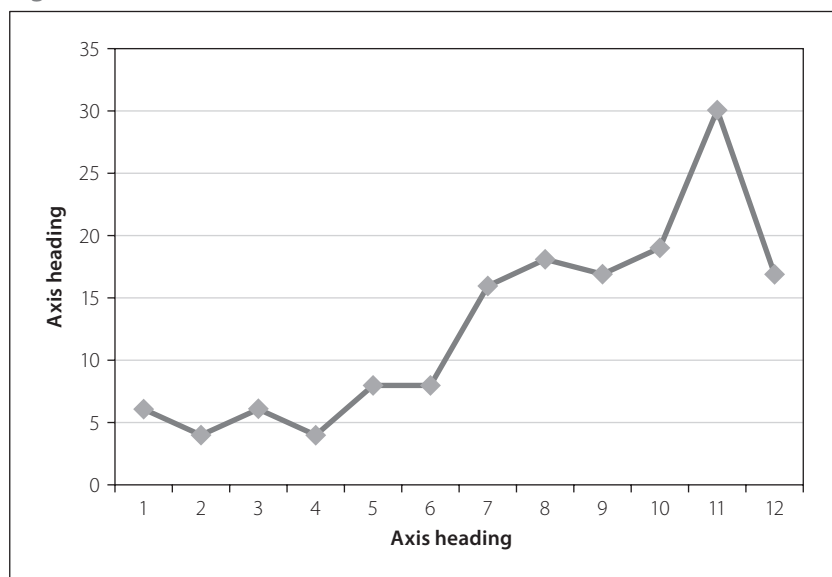
Table 2 Overall Hits and Relevant Articles

Total Hits: 16,793						
Group Hits: 1,447					Country Hits: 15,345	
DCs + I	LICs + I	LICs + D	LDCs + I	LDCs + D	(A...Z)+I	(A...Z)+D
474	33	648	12	273	351	14,994
First filter: abstracts						
50	5	38	12	1	164	n.a.
Second filter: full texts						
24	3	24	4	1	96	n.a.

There are two shortcomings associated with this methodology. One is that the focus on ‘innovation’, although buffered by the inclusion of ‘development’, risks losing information from fields of enquiry that are implicitly concerned with technical and other changes without using the terminology of innovation. In that sense this review is not only about how much we know about innovation in low-income countries, but how important LICs have been as an object of enquiry to innovation studies in the last decade, after innovation systems analysis has slowly been extended to transition and developing countries. The other is that the search is limited to ISI accredited journals. Both limitations will be dealt with in future work.

DESCRIPTIVE RESULTS

Much like innovation research in general and innovation research on developing countries in particular, LICs featured more prominently in innovation research from about 2003 than in the previous six years (see Figure 1). Average annual publications more than tripled from six in 1997–2002 to 19 in 2003–2008. Although it is impossible to draw precise inferences between the global commitment to reduce poverty and research output, it is interesting that half the articles published in 2001 address issues directly linked to the MDGs (Allison and Ellis, 2001; Ansaloni et al., 2001; Mak, 2001; Wheeler and Berkley, 2001).

Figure 1 Articles on Innovation in LICs, 1997–2008

Source ISI Web of Science

Between 56 (single-authored publications) and 71 per cent (multi-author publications) originate in universities and other research organisations outside the LICs. Overall only one in four co-authored articles involves a researcher based in a LIC and of these less than one in three was a lead (i.e., corresponding) author. Our research does not allow identification by nationality; hence it is not possible to say what proportion of LICs authors works outside the home country. Within LICs, one in four co-published papers involves authors from universities or research organisations and industry or other entities.

The geographical coverage of the research roughly corresponds with the weight of the LICs across the three continents (see Table 3). Analyses about East and West African countries dominate, accounting for half the total. The next group is countries in South Asia. Nigeria, Tanzania and Pakistan are the most frequently covered countries; but even in their case the total number of articles is low. Some LICs from (in alphabetical order) the Central African Republic to Yemen do not feature at all and others such as Cambodia or Rwanda—only once.

Two thirds of the articles focus on the two perhaps most important issues in low-income countries, namely agriculture and health. Other primary livelihood topics include water and sanitation, and energy. Manufacturing is a less prominent topic, reflecting the relative predominance of primary activities in the economies of most LICs (see Table 4).

In sum, innovation research on the LICs increased from a very low level toward the end of the last decade. Most researchers published from

universities and research organisations outside LICs. Even as co-authors, LICs researchers played a relatively marginal role. Less than a handful of countries attracted attention with some consistency; many do not feature at all. Livelihood issues – how to get food on the table and keep disease at bay – dominate the research agenda.

INNOVATION STUDIES CONCEPTS IN THE LITERATURE ON LICs

Innovation studies have come to be accepted as a field of enquiry. It attracts thousands of researchers around the world who, at times in dedicated re-search institutes, pursue similar research questions in the context of more or

Table 3 Geographical Coverage of Innovation Articles

Regions and countries	Number of publications	Percentage
Africa	96	63
East Africa	35	23
Kenya	9	6
Tanzania	11	7
Uganda	3	2
Ethiopia	5	3
West Africa	34	22
Ghana	5	3
Nigeria	16	10
Southern Africa	11	7
Zimbabwe	5	3
Central Africa	0	0
More than one region	16	10
Asia	33	22
South Asia	22	14
Bangladesh	4	3
Nepal	6	4
Pakistan	11	7
Southeast Asia	7	5
Vietnam	4	3
Central Asia	2	1
More than one region	2	1
Africa And Asia	8	5
South America	0	0
Not Specified	15	10
Total	152	100

Source: ISI Web of Science

Table 4 Sectoral Coverage of Innovation Articles

Sector	Number of publications	Percentage
Agriculture	54	35
Health	40	26
Agriculture and health	3	2
Agriculture and energy	2	1
Agriculture and manufacturing	1	1
Manufacturing	21	14
Information technologies	7	5
Water and sanitation	5	3
Education	5	3
Energy	4	3
Financial services	3	2
Other	7	5
Total	152	100

Source: ISI Web of Science

less agreed conceptual frameworks, meet at regular conferences and publish in a defined set of journals (Fagerberg and Verspagen, 2009; Martin, 2008). The question is whether and how the analysis of innovation in LICs relates to this body of knowledge. This refers not just to theory and methodology, but also to the kinds of issues innovation studies is particularly interested in. This includes the type of innovation, the origin of knowledge and its transmission, the nature and scope of networks and institutions within which innovations are generated and diffused, and how this research informs policy.

'Innovation studies' is of course only a subset of the literature concerned with innovation. Other fields of inquiry, each with its own theories, also contribute to researching the determinants and effects of innovation. Since the allocation of individual articles by theoretical framework to specific fields is complicated and somewhat subjective, it shall suffice here to show the spread of journals across which innovation in LICs is reported. 'Innovation journals' are those contained in the surveys by Fagerberg and Verspagen (2009) and Martin (2008) which consist of journals that academics in innovation studies regard as important and which include some of the most highly cited publications in the field.

Articles in innovation journals account for only ten per cent of the total, and thus fall between the share of engineering and development journals. Agriculture and health journals make up 41 per cent. The remainder is a wide variety of social science journals. Dispersion is a hallmark of the literature on innovation in low-income countries. Eighty-one journals carried

only one article each, and the 105 journals covered in this review – on average – fewer than two. Dispersion also affects the coverage of LICs within each field; only three journals – *Technovation*, *Health Policy & Planning*, and *African Journal of Biotechnology* – carried more than five articles on the subject. Based on this information alone one can surmise that there is not much of a conversation about innovation in LICs going on, not within and let alone across fields. Hence not only is innovation in LICs an under-researched topic, but there is no evidence that the topic has carved out a niche in the established literature.

Adding to this is that 19 per cent of the articles in the database are descriptions of development projects that use no theoretical framework whatsoever, and therefore are impossible to include in a theoretically informed discussion of either the determinants or the impact of innovation. Only one article was dedicated to a literature review itself (Reed, 2007). It reviews the change from technology transfer to participatory technology development, involving scientists and extensionists alongside farmers, in African agroforestry.

Most articles are empirical. Methodologically, about twice as many (41%) are based on quantitative data, often obtained through surveys, as on case studies (21%). Much of the remainder (31%) consists of overviews of specific issues or essays. The type of innovation discussed includes organisational (36%), process (20%), product (19%), or process and product (7%). New products include everything from GM crops (e.g. Anderson and Jackson 2005) to displacement pumps (Walde and Short, 2007) in agriculture, and vaccines (e.g., Acosta et al., 2004; Breman, Alilio, and Mills, 2004) and surgical instruments or screening techniques (e.g., Franco, Duarte-Franco and Ferenczy, 2003; Kumar and Tynan, 2005) in health. New processes involve farming techniques such as seeding, intercropping and forage development (e.g., Ayele, 2003; Ijoyah, Aba and Ugannyan, 2006) or the transfer of global scientific knowledge (e.g., Asbroek et al., 2005). Many organisational innovations concern participatory approaches in development assistance, involving user communities (e.g., Philpott, Maher and Grosskurth, 2002). Others include health systems (e.g., Travis et al., 2004) or disease management (Rodriguez et al., 2005), building partnerships to meet the research needs of LICs (Hyder *et al.*, 2007), managing pesticides, changes in curricula (e.g., Williams, 2007), and so on. A few papers dealt with organisational innovation at the firm (e.g., Mugisha, Berg, and Muhairwe, 2007), industry or sector (Gouws et al., 2004) or community level in the context of building capabilities (e.g., Knight, Weir and Woldehanna, 2003).

One would expect that most knowledge relevant for learning, upgrading and innovation in LICs has external origins. This is because for many problems faced by LICs there is a solution that in principle can be transferred

even though their limited absorptive capacities can prevent effective knowledge transmission (e.g., Bosetti, 2008; see also Akhtar and Gregson, 2001; Daly, 2000). For example, Asbroek et al., (2005) discuss the implementation of global lung health knowledge in local practice in Nepal, whereas Gladwin, Dixon and Wilson (2002) analyse the reason for the rejection of an externally designed health management information system by its intended users. Other such cases include the adoption of WHO guidelines on the management of childhood diseases by health workers (Gouws et al., 2004) and the relationship between (external) research and (local) policy (Philpott, Maher and Grosskurth, 2002; van Kammen, De Savigny and Sewankambo, 2006). Breu, Maselli and Hurni (2005) describe how global scientific and local knowledge were integrated to chart development plans for a region in Tadjikistan, and Veitayaki and South (2001) describe a similar process in the Pacific Islands.

The majority of the articles covered in this review do not bear out the centrality of external knowledge. Although foreign organisations – for example the World Bank, the World Health Organization, international NGOs, and international research centres such as the International Centre for Research in Agroforestry, International Centre for Tropical Agriculture, and the International Rice Research Institute – are the single most important source of knowledge transmission (24%), collectively more learning emanates from local sources, namely firms (10%), communities (9%), government (8%), organizations (7%), and universities (5%).⁴ For example, James (2004) focuses on innovators who use the internet in new ways. Barker (2004) reports on the diffusion of innovation originating from foreign donors through local practices of dissemination such as voodoo in Haiti. Konde (2004) describes a Zambian internet service provider that originated as a university spin-off.

Foreign universities and firms play much less of a role, at least in terms of frequency. The literature does not allow to assess the differential impact of these transmissions, and it cannot be excluded that this finding reflects a bias of the research rather than a precise assessment of the relative significance of – and the interplay between – local and international knowledge. Undoubtedly this finding sits uncomfortably with a standard presumption in innovation studies, namely that the absorption of external knowledge is key for upgrading. Possibly researchers of innovation in LICs are more interested in local diffusion of technology rather than where it came from or who adopted it in the first place. If this is the case, then the role of global knowledge networks and their impact on innovation in LICs is not well understood.

In what is probably the biggest departure from traditional innovation studies, only roughly one in five articles addresses firms or clusters and their products, upgrading or intellectual property protection strategies. The

great majority of articles has completely different units of analysis, ranging from individual (women) farmers via households and communities to more complex entities such as seed or health systems. This influences the questions researchers ask about innovation, how they address them methodologically, and -- most importantly -- what conclusions they draw on the determinants and impacts of innovation.

By and large, the firm-centred work is not much different from innovation research in middle-income countries. It concerns the upgrading of capabilities (Abereijo et al., 2007; Goedhuys, 2007; Marcelle, 2005; Murphy, 2006, 2007; Oyelaran-Oyeyinka and Lal, 2006), and the roles played by diffusion (Uddin, 2006), networks (Chipika and Wilson, 2006), spatial agglomeration (Caniels and Romijn, 2003a,b), R&D (Prajogo et al., 2007), and liberalisation (Howcroft and Ataullah, 2006) as well as the international environment more generally (Byfield, 1997; Kaplinsky, 2007; Meagher, 2007) for learning. Analyses also focus on adaptation strategies in the face of new technologies such as e-commerce that face significant barriers in LICs (Huang et al., 2003; Kshetri, 2007; Nguyen and Barrett, 2006), the interaction between local capabilities and global value chains (Hau and Evangelista, 2007; Nadvi and Halder, 2005), and IPR strategies for both profitable and neglected diseases (Ito and Yamagata, 2007). Some look at the opportunity for S&T or other innovation support policy to influence firm upgrading (Adegbite, 2001; Adeoti and Adeoti, 2005; Ilori et al., 2002; Storm, 2008). Organisational approaches to firm performance include the use of contract incentives in water utilities (Mugisha, Berg and Muhairwe, 2007; Mugisha and Berg, 2008), food companies (Ilor, Oke and Sanni, 2000), and networks in SME furniture manufacturers (Murphy, 2002, 2003). Specific attention to poverty is rare, as with repercussions for the poor of the privatisation of utilities (e.g., Hall and Lobina, 2007).

By contrast, the majority of the literature addresses innovation in rather different and – at least to the innovation studies community – unfamiliar ways. A number of articles focuses on individuals. Binswanger (2007) discusses rural people as key actors in their agricultural and rural development, albeit dependent on a conducive institutional environment. Kincaid (2000) analyses data about the change in the use of modern contraceptive methods in a panel of married women in Bangladesh and finds that new ways of thinking about fertility, rather than merely increase in per capita income, accounts for modifications of reproductive behaviour which is based on a multi-stage, innovation-decision process. Ogunlana (2007) explains the factors behind the decision of women farmers in a state of Nigeria to adopt innovative ways of planting leguminous trees interspersed with crops to save on inputs, reduce competition from weeds, and conserve soil.

The next level of aggregation is households. Mehrotra and Biggeri (2005) study how industrial outwork influences the capabilities of homeworkers in India and Pakistan that produce consumer non-durables for global value chains. They find that local development – instead of mere exploitation – is only likely to take place if governments monitor the process, afford education and social protection, and facilitate joint action, for example in the form of community-based child care to allow the older girls to attend school. Allison and Ellis (2001) report how households engaged in small-scale fishing respond to resource fluctuations through part-time alternative livelihood strategies and reliance on remittances, and underline that this is a much more effective adaptation than attempts to professionalise the fishing industry. In Ethiopia, forage innovations improved the welfare of households implementing small-scale, mixed farming systems, provided community participation was enlisted and socioeconomic constraints were not too severe (Ayele, 2003). Further, education plays a role in the adoption and diffusion of agricultural innovations. More precisely, education favours early adoption, and social networks then favour copying by the lagging households (Weir and Knight, 2004).

Many articles address entire communities. They focus, *inter alia*, on innovation in the context of sustainable livelihoods (Butler and Mazur, 2007; Eklund, Imai and Felloni, 2007; Masangano and Miles, 2004; Mudhara, Hildebrand and Nair, 2003; Nath, Inouye and Myant, 2005; Pringle, Bajracharya and Bajracharya, 2004). For example, Mak (2001) describes how Cambodian rice farmers experimented with technology originally developed for application under different conditions. Abay, Waters-Bayer and Bjornstad (2008) study the importance of farmer-developed varieties of barley for successful local development. Another area is learning processes in local resource management and environmental awareness (Abidi-Habib and Lawrence, 2007; Dixon, 2005; Dunn, 1998; Hadi, 2003; Petit, 2003; Richards, 2006; Spaling, 2003).

In this context, differentiation across seemingly homogeneous communities in their response to innovation, as well as similarities between heterogeneous communities, are a recurrent theme. For example, McKay *et al.*, (2007) explain how poorer families in Nepalese villages are inherently more risk-averse and thus less prone to experiment with new technologies. Similar findings result from an analysis of farmers in Ethiopia (Knight, Weir and Woldehanna, 2003). Romani (2003) shows how ethnic origin influences the knowledge transfer among farming communities in Cote d'Ivoire. Rowland and Nosten (2001) report lessons from the treatment of malaria obtained in Karen and Afghan refugee camps for emergency situations elsewhere. Compared to innovation research in middle-income countries, there is rather little research on value chains. Sanginga *et al.*, (2004)

describe how the success of creating local value chains linking farmers to markets depends on sustainable community agro-enterprise and the use of participatory approaches to the identification of market opportunities and enterprise selection. Similarly, Kaaria et al., (2008) discuss pro-poor market linkages and benefits within and across households.

In much of this work, 'participation' – not the equivalent but something similar to demand or user-driven innovation familiar from traditional innovation studies – plays a role (e.g., Chataway and Smith, 2007; Kyem, 2000; Maranga, 1999).

Innovation systems are conceived as narrow (only comprising the science and technology system) or broad (including all actors relevant for economic development). They are further distinguished in terms of formal (e.g. intellectual property rights) and informal (tacit acknowledgements of rules governing social and economic interaction) institutions (Jensen et al., 2007). Although a narrow system and formal institutions are easier to identify and measure, they are not necessarily more relevant, least of all in developing countries with underdeveloped institutions. Of course informal and formal rules are likely to interact, but in order to understand this interaction, the informal sphere in the broader context must be properly assessed first. In fact twice as many articles focus on the broad system and 58 per cent deal with informal or jointly with informal and formal institutions.

In agriculture, DaSilva, Baydoun and Badran (2002) underline that biotechnological innovations in the formal sector have not made more inroads in LICs because of the limited exposure of farmers to biotech education and capability building. Similarly, Sonaiya (2007) stresses the need for knowledge about the highly pathogenic avian influenza (HPAI) virus to be linked with capability building in family poultry farming and thus food security. Such shortcomings can be countered with a combination of diagnostic and technographic studies of local needs to inform the search for solutions (Hounkonnou et al., 2006; Roling et al., 2004). Many articles critically evaluate the appropriateness of technology (e.g. Nederlof and Dangbegnon, 2007). External knowledge may be too expensive (Kamidi and Kamidi, 2005) but need not (Poussin, Diallo and Legoupil, 2006) and can also be tailor-made to local circumstances (He et al., 2008; see also Hvinding, 1998).

Diffusion of innovations is not necessarily an automatic process but needs to be anticipated, organised (Chitere, 1998; Ducrot and Capillon, 2004) and properly resourced (Faturoti et al., 2006; Ijoyah, Aba and Ugannyan, 2006; see also Njuguna, 1997). Extension plays a big role (Thangata and Alavalapati, 2003). Financial innovations such as renewable energy funds may allow project funding to come forward even in severely resource-constrained conditions (Monroy and Hernandez, 2008; see also Sebitosi and

Pillay, 2001). The structure and function of actor networks is central to the introduction and diffusion of new technologies (Caniëls and Romijn, 2008; see also van Eijck and Romijn, 2008). Institutional innovations include marketable property rights which afford poor people with an opportunity to minimise risk exposure through acting as a buffer (Zimmerman and Carter, 1999; see also Adjei-Nsiah et al., 2008; Taylor, 2004). Weaknesses of the agro-innovation system, especially linkages between actors, are the subject of several contributions (e.g., Agwu, Dimelo and Madukwe, 2008; Faturoti et al., 2007; Lanteri and Quagliotti, 1997; Turrall, Malano and Chien, 2002).

A number of contributions originate in agronomy and are more technical in nature. The diffusion and adoption of such innovations directly benefit from the insights described above. This includes soil (Odame, 1997), crop (Gathumbi et al., 2003; Qi et al., 1999; Westerman et al., 2006) and fallow management (Gathumbi et al., 2002; Tarawali et al., 1999), as well agricultural machinery (e.g. Amonov, Pulatov and Colvin, 2006; Badmus, Adeyemi and Owalarafe, 2005).

In health, a number of articles deal with system design (e.g., Bloom, Standing and Lloyd 2008; Peters and Chao, 1998), including organisational innovations (Goodman et al., 2006, Gulzar and Henry, 2005; Igira, 2008; Meessen et al., 2006; see also Fyvie and Ager, 1999) and the research-policy interface (Hyder et al., 2007). De Souza et al., (2008) even discuss the linkages between health and other systems, such as land and resource use. Several authors ask why system performance is unsatisfactory, for example in reducing child mortality (Bryce et al., 2003); others propose how good models can be effectively implemented through innovative ways of innovation diffusion, such as serial dramas broadcast on radio to prevent HIV/AIDS (Galavotti et al., 2008; see also Nyonator et al., 2005).

Some critique the adequacy of global reforms in LIC contexts (e.g., Yazbeck, 2004). Others focus on solutions to the lack of R&D into tropical diseases, such as through public-private partnerships (Wheeler and Berkley, 2001) or advance-purchase agreements (Berndt and Hurvitz, 2005). Several articles stress the need for community engagement and social networks to obtain stated goals, for example in reproductive and child health (Phillips, Bawah and Binka, 2006), infant HIV prevention strategies (Burke, 2004), the dissemination of anti-malaria nets (Rubardt et al., 1999), or in reaching out to migrant workers (Poudel et al., 2007). As in some agricultural papers, the diffusion of innovation is discussed in relation to the availability of adequate resources (e.g. Awonoor-Williams et al., 2004; Fraser-Hurt and Lyimo, 1998; Mufumba et al., 2007).

Innovations in medical devices or procedures relevant for LICs discussed in the literature – mostly because they are cheaper and safer to use than their high-income country equivalents – include a microchip based CD4

counting method (Rodriguez et al., 2005), organisationally modified catheter interventions for heart disease (Kumar and Tynan, 2005), new indicators for smear-negative pulmonary TB infections (Siddiqi, Lambert and Walley, 2003), and an innovative Caesarean section (Ansaloni et al., 2001).

A few articles not directly concerned with either agriculture or health, deal with education. For example, this includes discussions of new ways of teacher training in Pakistan (Khamis and Sammons, 2004, 2007), attempts to improve reading facilities of students in Malawi through new project design (Williams, 2007) or to introduce innovative curricula in Zimbabwe (Nhundu, 1997).

About 85 per cent of this literature is policy-oriented or -relevant. Advice is directed primarily at governments in LICs, either by themselves (33%) or jointly with other organisations (52%). Somewhat in contrast with the attention being paid to the broad innovation system, users such as farmers (1%), local firms (1%), or business support entities (1%) are much less targeted than public sector users, whether local or foreign.

CONCLUSION

This literature review asked what role STI exactly plays in LICs, and what we know about innovation in these countries. This refers especially to insights generated from within the field of innovation studies. These are not identical questions – a lot of innovation might go on without being analysed and, for that matter, understood. However the expectation was that in view of the generally agreed need of STI for growth and development in poor countries, there would – or should – be a considerable body of work on the issue. It acknowledged, however, that innovation in LICs might be rather idiosyncratic, mostly only locally relevant, and thus of less interest to a global audience, thus depressing the production of knowledge about innovation in the LICs. In sum, the simple answer to the first question is that innovation does take place in LICs and that, although not always successful, it affects development in various ways. Yet the knowledge base about these phenomena is small and rather fragmented.

This is not a trivial finding. By 2004, one out of five social science articles carried ‘innovation’ in its title (Fagerberg, 2005, Figure 1.1). Hence there is no question that innovation matters and is researched accordingly. Although by general consensus it also matters in poor countries, each year at best sees a few dozen papers published on the topic. Not only is there no single journal dedicated specifically to LICs, but coverage of LICs even in the most exposed journals is rather slim. In addition, most of this research is country-specific and focuses on just a handful of LICs in Africa. By

implication, comparative analyses are few and far between and patterns or similarities across countries largely unknown. This is therefore very different from, say, research on the BRICS countries or the transition economies of Eastern Europe and other parts of the former Soviet Union (e.g., Cassiolato and Vitorini, 2009), not just in innovation research but in many other fields of inquiry as well. The flip side of the predominance of country-specific empirical work is a dearth of theoretical or conceptual work asking how or why LICs might be different as a group of countries, and what accounts for their internal differences.

Within this group, innovation studies only play a marginal role. Although there are parallels between firm-centred work in LICs and MICs in terms of theoretical frameworks, methodologies, and findings (cf. Lorentzen, 2009), innovation studies with its traditional focus on manufacturing does not correspond with the mainstay of research on innovation in LICs which focuses on agriculture and health. In large part, this is because traditional innovation studies focuses on the firm as a unit of analysis, while livelihood-related researchers address issues at the level of individuals, households, or communities.

Despite this gap, some overlap exists, though mainly in the area of terminology. Local capabilities, forms of learning, and linkages are popular topics throughout. They are also the issues through which researchers from the different disciplines could enter into a dialogue about innovation in LICs. One theme in need of attention is the relationship between (external) technology transfer and (local) diffusion of innovation. These two areas of inquiry rely on different literatures that have mostly ignored each other (Cottrill, Rogers and Mills, 1989). In LICs, this comes at the cost of missing crucial insights of more comprehensive and complex accounts of socioeconomic upgrading in largely poor contexts (Lorentzen and Mohamed, 2010). Also, the importance of 'community involvement' in development projects in the livelihood literature is none too different from the attention given to user-driven innovation in the innovation literature.

In view of the large number of LICs and the little research that is available about most of them, it is not realistic to expect a sudden increase in the geographical coverage of the literature. It is feasible though to summarise work done so far and try to give the existing body of knowledge more theoretical and conceptual depth.

NOTES

- 1 The Bottom Billion are inhabitants of countries with a gross national income per capita of less than \$995. The UN recognises 49 such low-income countries; 33 in Africa, 15

- in Asia, and 1 in Latin America. Roughly four to five in ten of these people live on less than \$1.25 a day (Chen and Ravallion, 2008).
- 2 For example, Bell's (2007) comprehensive background paper for UNCTAD's 2007 LDC Report, on the development of innovative capacities, references rather little research on LICs, such as Rhee's (1990) article on Bangladesh's garment exports. Most of the analysis is inferred from writings about more or less successful middle-income countries.
 - 3 LDCs AND Innovation at 33 per cent is an exception because it is based on only 12 hits overall.
 - 4 Of course these entities in turn are likely to have absorbed external knowledge, but this process is less analysed.

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Human Capital, R&D and Endogenous Occupational Choice

Loesse Jacques Ezzo

SUMMARY

The paper explores the interaction between capital markets imperfections and the agents' occupations in a technologically non-advanced country. We then build a two-period overlapping-generations growth model with heterogeneous agents. We suppose that agents inherit ability and a technique of production from their parents. We show that when information in the capital markets is imperfect the occupational choices of agents are endogenous. We also find that there are two endogenous thresholds of ability which allow distinguishing lenders, R&D innovators and implementers who produce intermediate goods with lagged productivity. Finally, the growth rate and convergence depend both on the level and the structure of human capital. Capital markets influence economic growth and convergence through technology.

INTRODUCTION

Most current theories of development economics show that capital markets are important in the financing of economic activities. They can increase the volume of investments by loans to agents and thus contribute to increase the level of employment, product and the rate of economic growth. But in an uncertain environment, where the risk on borrowers, asymmetries and monitoring and agency costs are important, the role of allocation of capital market resources is strongly undermined. Indeed, risks related to borrowers, asymmetries and high agency costs explain in some countries the limited access of a great number of agents to credit. In this context, what can be the effects of capital market on economic activities? How does it influence the occupational choices of an agent?

Economic literature is largely interested in the role of capital markets in the occupational choices of an agent. In macroeconomics, capital markets are studied according to two types of models from the point of view of the nature of the endowment. A first range of models supposes that individuals inherit heterogeneous endowments while a second range of work considers that the source of the heterogeneity of agents is their parents' human capital. In models where individuals have heterogeneous endowments, an agent has to decide if she will invest in human capital or not. It is shown in these models that capital market imperfections negatively influence the distribution of the wealth.

Indeed, in the presence of asymmetries, the debt rate of capital is lower than the credit rate because of the existence of monitoring costs. Thus, only the agents who are sufficiently rich to buy or pay an interest rate higher than the loans can invest in human capital. These individuals become skilled workers and those who are not educated remain unqualified (Lloyd-Ellis, 2000). Galor and Zeira (1993) show that throughout this mechanism, the initial distribution of the wealth determines the aggregate investments in human capital and the long run income per capita. If the initial inequality is sufficiently low, equilibrium with equity is observed according to that all the workers have the same wage and the income per capita will reach its highest level.

The initial levels of inequality allow determining the properties of the long-term equilibrium (Banerjee and Newman, 1993). In a more general model, Lloyd-Ellis and Bernhardt (2000) consider agents whose heterogeneity is the entrepreneurial efficiency and the level of physical capital endowment. The effects of wealth and ability are different and vary as the economy develops. They conclude that at the first stages of development, the inherited wealth is the main determinant of occupational choice because rich agents can invest in physical capital. But at the later stages, the entrepreneurial efficiency is more important. Indeed, when the entrepreneurial efficiency is low, the interaction between credit constraints, the entrepreneurial efficiency and the equilibrium wage generates cyclical wealth distributions.

In a second range of models, the choices of an agent are rather due to the parents' ability. In this context, Ghatak, Morelli and Sjöström (2001) build a model in which individuals have to work first and then save before acquiring sufficient wealth to invest in their own project. An agent, once old, can choose to remain a worker or an entrepreneur. These authors show that the existence of credit constraints in an economy is an incentive to work. Indeed, the poor young agents exert more effort in order to acquire income at least as large as the revenues of the entrepreneurs. In case of moral hazard, an increase in the agents' effort raises the human well-being.

In the two types of models, the effects of capital market depend on the distribution of the heritage. However, these models do not take into account another important source of economic growth, which is productivity. In this article, we fill the gap considering that agents inherit not only talent, but also of a technique of production. Especially, the main issue is how do inequality of ability and its interaction with capital markets access affect occupational choices of agents, economic growth and aggregate technological change?

This article aims at providing a theoretical analysis of the dynamics of technology gap in an endogenous growth model, and mainly tries to show the importance of capital markets for occupational choices and economic growth. Specifically, we first show that capital markets imperfections lead to a segmentation of the agents according to ability. More clearly, there are two thresholds of ability that distinguish three types of agents: strictly lenders, implementers or imitators and innovators. In this way, occupational choices are endogenous. Second, we highlight a mechanism by which capital markets affect the economic growth rate and convergence of a backward country. Third, we show that the distribution of human capital and credits to research and development sectors are important determinants for economic growth and convergence.

The theoretical framework is a model with overlapping-generations of agents living in two periods. This model is in the line of Aghion, Howitt and Mayer-Foulkes (2005). Considering a multi-country model,¹ Aghion et al., (2005) show that a country in which financial development indicators are higher than a credit threshold converges in the long-run towards the world technology frontier. In this economy, financial development positively influences the ratio of the gross domestic product per capita to the technological frontier. In Aghion et al., (2005) model, agents can invest in R&D to produce intermediate goods. The innovation rate depends only on the final good of the economy and is the same for every agent at equilibrium. The intra-country inequality is not analysed; only the dynamics of the technological change is studied. However, this model shies away human capital which enables to adapt to technological change (Nelson and Phelps, 1966). The mechanism through which capital markets affect economic growth is not perceptible. Thus, we introduce into the model by Aghion et al., (2005) the heterogeneity of agents and innovation rates which depend both on the final good and human capital. Individuals have the same preference and consume all their wealth at the second period. During their youth, they work in a final good production sector and earn the same wage depending on the mean productivity of the economy. They accumulate knowledge according to the levels of human capital inherited and the distance to the technological frontier. At the second period, agents

can be directed in two different sectors: the sector of the R&D and the implementation one. In the sector of implementation, agents produce intermediate goods with the mean productivity of the economy of the previous period. Banks ensure financial intermediation. Agents investing in R&D sector finance their activities with credits allocated by the bank system. In this context, the first result relates to the existence of a threshold of human capital enabling discrimination against agents according to their occupations. This threshold is that agents having a level of human capital higher than this threshold (qualified), borrow money to invest in R&D activities while agents whose level of human capital is below the threshold (less qualified), lend their wealth and produce intermediate goods with the previous mean productivity of the economy. Secondly, we show that competitive equilibrium is characterised by a decreasing set of interest rates and increasing investment levels as agents become more and more skilled. On the other hand, for the less talented agents the risk of default is so high that banks grant fewer credits at higher cost. We also show that the economic growth rate and convergence of a backward country depend not only on the distribution of human capital but also on the ratio of credits to the technological frontier.

The remainder of the paper is organised as follows. Section 2 presents the literature linked to our study. Section 3 describes the basic environment. Especially, it presents the process of human capital accumulation, and firms' and banks' behaviour. In section 4, we characterise the equilibrium contracts in full information, when asymmetries of information are present in the capital markets and highlight the endogenous occupational choices of the agents. Section 5 describes the dynamics of the technological gap. The conclusion follows then.

PREVIOUS STUDIES

From a theoretical point of view, our contribution is related to at least three important fields of economic literature.

- **Occupational choices:** In models with capital markets, occupational choices of agents are endogenous and asymmetries negatively influence the economic growth rate. We have, among other works, Banerjee and Newman (1993), Galor and Zeira (1993), Galor and Moav (2004), Aghion and Bolton (1997), and Piketty (1997). These models generate poverty traps because of the existence of non-convexities in the production and externalities. Other evidence is presented by Ghatak et al., (2001) or Ghatak et al., (2002). They suppose that agents can

also be different according to their entrepreneurship abilities. Ghatak et al., (2001) show in this context that asymmetries are an incentive to work and can increase the well-being of an agent. Thus, any policy of reduction of asymmetries can be negative for agents' well-being. In these models, agents have the same technology and, contrary to ours, the same capital cost. Furthermore, they do not consider technological change and no possibility of economic growth and long-run convergence.

- **Endogenous growth models:** A technologically backward country cannot implement a technique of production coming from abroad without an investment in human capital. The receiving country cannot just take foreign technologies off the shelf and implement them costless. Instead, the country must make technology investments of its own to master foreign technologies and adapt them to the local environment, because technological knowledge is often tacit and circumstantially specific (Aghion et al., 2005; Crifo, 2008). These investments play the same role as R&D as in Grossman and Helpman (1991) or Aghion and Howitt (1992) endogenous growth models. These investments give place to new technologies in the country in which they are implemented. Thus, as showed in Cohen and Levinthal (1989), each technology transfer is accompanied by an innovation in the host country. The more expensive such adoption of technology the more advanced or sophisticated is the technique to be transferred. This article highlights the constraints related to the technology transfers, especially towards developing countries.
- **Credit rationing:** The literature about credit rationing originated from Stiglitz and Weiss (1981). The most prominent model presented in Stiglitz and Weiss (1981) is the one with a borrowers endowed with projects with identical mean rates of return and with non-observable riskiness. They show that in the presence of asymmetries, a loan market may be characterised by credit rationing in equilibrium. Therefore, there is a negative relationship between interest rates and expected returns of banks. However in Stiglitz and Weiss (1992), this relationship can be non-negative. Indeed, even if all agents have the same utility function and face the same investment opportunities, wealthier individuals would both be willing to put up more collateral and undertake riskier projects than would less wealthy agents if there was decreasing absolute risk aversion. Other evidences are provided by Bernhardt (2000), De Mezza and Webb (1987), for example. One of the limitations of this range of studies is that it does not consider technological change, which excludes the possibility of long-run economic growth.

THEORETICAL FRAMEWORK

This section aims at describing agents' behaviour using a two-period overlapping-generations model. Specifically, we present how individuals accumulate human capital and how production firms and banks behave when interacting with agents.

Human capital accumulation: One of the components of the Nelson-Phelps hypothesis suggested that the rate at which the gap between the technology frontier and the current level of productivity is closed depends on the level of human capital. This was a break with the view that human capital is an input into the production process. In this section, we propose a human capital accumulation function depending on the gap between the technological frontier and the current level of technology reached by a country.

We follow Aghion et al., (2005) and suppose that the world is composed of countries that do not exchange goods and factors but do make use of each other's technological ideas. We consider an unspecified economy among the countries which we call national country. The national country is populated by overlapping-generations of heterogeneous agents living two periods. Individuals are uniformly distributed on the continuum. Each agent of type i inherits ability from a parent (knowledge or know-how) and increases ability while working in a general sector, allowing producing the final good of the economy. At the end of the period, ability achieves the level. An individual's ability can also depend on knowledge and the sector of occupation of ascendants (see for example Galor and Tsiddon 1997). Finally, agents have heterogeneous human capital endowments. For a survey on human capital accumulation, see for example, Lucas (1988), D'Autume and Michel (1994), Aghion and Cohen (2004), Galor and Moav (2000, 2004), Tamura (2006). Finally, second period ability evolves according to the relation:

$$\theta_{t+1}(i) = [\theta_t(i)]^\sigma [\delta_t]^{1-\sigma} \quad (1)$$

$\delta_t = \frac{A_t}{A_t^{max}}$ is a measurement of the technological gap between the technological frontier and the current level of the technology in the national country; it can be seen as the distance to the technological frontier of the national economy. A_t and A_t^{max} are respectively the technological level of the national country and the technological level of the leader country in the world. This formalisation is an alternative of what has been used by Aghion and Cohen (2004) and indicates that the previous technological frontier positively influences current human capital level with an elasticity of $(1-\sigma)$. Moreover, human capital increases as the national level of technology tends to be close to the technological frontier. A young agent earns a

wage which represents the outcome of her work during her first period of life. During the second period of life (period $t+1$), each adult agent gives rise to a child (the demographic growth rate of the economy is null). During this period, she can invest in R&D activities and innovate by increasing the quality of the intermediate good of her sector (see Aghion and Howitt, 1992, or Grossman and Helpman, 1991) or saves her wage in the capital market. To simplify, the utility function of an agent is equal to her second period consumption. In this economy, the only source of inequality is the individual's level of ability.

Firms: This sub-section describes the behaviour of the firms in the general sector in which is produced the final good and intermediate goods. It also presents how banks behave and details R&D activities enabling to innovate.

The general sector: There is a final good in the economy, which is used for consumption and as capital good in the intermediate sectors. This final good is produced by labour, current technology and a continuum of specialized intermediate goods. It is also used as input in research and development (R&D) and is considered as numéraire. The production function of the firm is:

$$Y_t = \int_0^1 L^\alpha A_t(j)^\alpha x_t(j)^{1-\alpha} dj, \quad 0 < \alpha < 1 \quad (2)$$

where $x_t(j)$ is the input of the latest version of intermediate good and $A_t(j)$ is the technical efficiency associated with it. For notational convenience, labour L is normalised to unity. The final good is produced under perfect competition. The demand for each intermediate good $x_t(j)$ and the wage of a worker verify the following equations:

$$p_t(j) = (1-\alpha) \left[\frac{A_t(j)}{x_t(j)} \right] \quad (3)$$

$$w_t = \alpha Y_t \quad (4)$$

A number of features of this production function are worth noting. First, α determines the degree of complementarity between inputs. Equation (4) shows that all the agents have the same wealth w_t at t . The price of each intermediate good is negatively linked to the demand of intermediate goods. Since $0 < \alpha < 1$, the elasticity of substitution between inputs, $\frac{1}{\alpha}$, is always greater than one.

The intermediate goods sector: The intermediate goods sector is composed of a continuum of enterprise owners. At any moment of time t , there is a single firm (monopolist) able to produce intermediate good $j \in [0,1]$. The

production of an intermediate good occurs at the second period of life of the owner. For each intermediate good j , the owner produces with the capital good used as input and the technical efficiency $A_{t+1}(j)$ associated with it. The level of technology $A_{t+1}(j)$ is specific to the corresponding intermediate good. The production of one unit of an intermediate good requires ε units ($\varepsilon > 1$) of the final good. The local monopoly chooses the quantity of good $x_{t+1}(j)$ which maximises her profit $(p_{t+1}(j)x_{t+1}(j) - \varepsilon x_{t+1}(j))$. The price of the intermediate goods is a mark-up, $p = p_{t+1}(j) = \frac{1}{1-\alpha}$. The demand for the j -type intermediate good can be expressed as $x_{t+1}(j) = \left(\frac{(1-\alpha)^2}{\varepsilon}\right)^{\frac{1}{\alpha}} A_{t+1}(j)$. The profit for the monopolist of the intermediate good of type j at $t+1$ is then:

$$\pi_{t+1}(j) = \pi A_{t+1}(j) \quad (5)$$

where $\pi = \frac{\alpha\varepsilon}{1-\alpha} \left(\frac{(1-\alpha)^2}{\varepsilon}\right)^{\frac{1}{\alpha}}$. It is shown that this profit increases with the technological level. The country's average productivity is seen as the sum of various technological levels associated with intermediate goods²:

$$A_t = \int_0^1 A_{t+1}(j) dj \quad (6)$$

The production function is linearly linked to the average productivity at t , that is to say $Y_t = \left(\frac{(1-\alpha)^2}{\varepsilon}\right)^{\frac{1-\alpha}{\alpha}}$, and the first period wage of an agent takes the form $w_t = wA_t$, where $w_t = \left(\frac{(1-\alpha)^2}{\varepsilon}\right)^{\frac{1-\alpha}{\alpha}}$.

There are two types of intermediate goods sector: the first type of intermediate goods sector (Sector of implementation) is composed of agents producing intermediate goods with the current technology level, A_t , and the second one (Sector of R&D) comprises agents who invest in R&D. Agents who invest in R&D can innovate and produce intermediate goods with a higher technical efficiency. For notational convenience, we suppose that the second period expected income of an agent who invests in R&D is higher than that of an implementer.

The research and development sector: The purpose of R&D activities is to increase the technological level for the production of each input, i.e. firms invest in quality-improving innovation. For each intermediate good j there is one person born each period $t-1$ who is capable of producing an innovation for the next period. This person is the j^{th} innovator in $t-1$, and if she succeeds (innovates) then she will be j^{th} the incumbent in t .

If R&D activities succeed for the j^{th} intermediate good, the j^{th} innovator is a monopolist for the intermediate good j with the technological level close to that of the leading country, $A_{t+1}^{\max}$. We suppose that $A_{t+1}^{\max}$ evolves at a constant rate g . This assumption of technology-jump is the manifestation

of active technology transfers, in other words domestic R&D uses ideas developed elsewhere in the world. Innovations last only one period. At the end of each period all the sectors have the average technology, i.e. technology behaves as an externality after one period. For ease of the presentation, physical capital completely depreciates after one period. Each firm innovates according to the owner's ability θ_{t+1} and the level of physical capital K_{t+1} . Physical capital K_{t+1} is an amount of the final good. Let us consider

$k_{t+1} = \frac{K_{t+1}}{A_{t+1}^{max}}$ the stock of physical capital in effective unit. The probability

of R&D success is denoted by μ_{t+1} . This probability μ_{t+1} depends on the level of the agent's human capital and the final capital good, $\mu_{t+1} = \theta_{t+1}$,

$\frac{K_{t+1}}{A_{t+1}^{max}} = \mu(\theta_{t+1}, k_{t+1})$. Division by the technological frontier A_{t+1}^{max} accounts for

the fishing-out effect which states that an investor has to spend more final good when the technological frontier is high to preserve her chances to innovate; R&D activities are capital good-intensive. A high level of investment in research and development increases the probability of innovation but at

a decreasing rate, i.e. $\mu_k = \frac{\partial \mu}{\partial k} > 0$ and $\mu_{kk} = \frac{\partial^2 \mu}{\partial k^2} < 0$. Otherwise, skilled

agents have more chances to innovate in their sectors. We suppose that ability and effective physical capital are complementary factors in the

innovation process, i.e. $\mu_{\theta k} = \frac{\partial^2 \mu}{\partial \theta \partial k}$. If R&D activities succeed (with prob-

ability μ_{t+1}), the technological level linked to the intermediate good j is

$A_{t+1}(j) = A_{t+1}^{max}$. However, in the case of failure (with probability $1 - \mu_{t+1}$), the

agent implements her intermediate good j with the national average level of technology, i.e. $A_{t+1}(j) = A_t$. This specification is in line with empirical stud-

ies. For example, statistical evidence of the importance of human capital for innovation is provided by Mohnen and Röller (2005) who show that lack of skills is the single most important innovation obstacle in a wide range of industries and countries. This result is confirmed by another recent study by Leiponen (2005). Indeed, using a panel of manufacturing firms, he finds that high technical skills are complementary with R&D collaboration and product or process innovation.

In the R&D sector, investors have two types of activities: first they invest in ought to improve the quality of intermediate goods (the total spending is K_{t+1}) and then produce actually their intermediate goods serving as inputs in the production of the final good. The latter activity provide a profit equals $\pi_{t+1}(j) = \pi A_{t+1}(j)$. Finally, the expected profit of an innovator is $\mu(\theta_{t+1}, k_{t+1}) \pi A_{t+1}^{max}$ while that of an implementer who does not innovate is πA_t .

The banking intermediation: The first period income can be used to finance R&D activities or also be invested in a perfect competitive capital

market composed of a large number of banks. There is in the national economy a large number of financial intermediaries competing in a perfect environment. The deposit rate R_{t+1} is supposed to be endogenous and deterministic. Banks collect savings and lend the funds collected to agents. An agent can be a lender or a strictly borrower. In the next section we will focus our concern on the behaviour of a borrower, that is to say the level of investment in R&D is so high that she is obliged to borrow from the capital market the amount $K_{t+1} - \omega A_t$ or $K_{t+1} A_{t+1}^{max} - \omega A_t$. Finally, banks compete in two dimensions: (i) the rate of interest charged, and (ii) the amount of investment in R&D K_{t+1} , so that the extent of the loan is determined by investment in R&D net of the first period wealth, $(K_{t+1} - w_t)$.

THE EQUILIBRIUM CONTRACTS

We compute in this section the equilibrium contract when the banking system has full information on the agents' characteristics and in the case of incomplete information. We hence show that in the presence of incomplete information in the capital markets, there are two ability thresholds that allow distinguishing of three types of agents in the economy; these are the low-skilled agents who are lenders, the middle-group agents who adopt current technology to implement the intermediate goods, and the high-skilled agents who invest in R&D.

Complete markets and optimal investment decision. The behaviour of a borrower: Banks are considered to be in a perfect competitive environment. They know exactly the individual ability of a given borrower and are able to verify *ex post* and without costs if investment in R&D succeeded or failed. They are in competition on the interest rate r_{t+1} and the amount of the loans $(K_{t+1} - \omega A_t)$ which they grant to agents. The level of investment in R&D and the interest rate depend on ability. Banks therefore offer the following type of contracts $(K_{t+1}(\theta_{t+1})A_{t+1}^{max} - \omega A_t, r_{t+1}(\theta_{t+1}))$ relatively to ability.⁵

When the investor of ability θ_{t+1} undertakes R&D activities, she can innovate with probability $\mu(\theta_{t+1}, K_{t+1})$ which increases with her ability. Her profit enables reimbursement of the initial debt. If she fails R&D activities (with probability $1 - \mu(\theta_{t+1}, K_{t+1})$), she does not have any profit and cannot refund her debt. The expected net profit of the agent is:

$$EU_{t+1} = \mu(\theta_{t+1}, K_{t+1})[\pi A_{t+1}^{max} - (1 + r_{t+1})(k_{t+1} A_{t+1}^{max} - \omega A_t)] \quad (7)$$

The indifference curves are concave. The slope of the indifference curve of a borrower in the plane is given by the relation (with $\lambda = \frac{A_{t+1}^{max}}{A_t}$):

$$\frac{dr}{dk} = -\frac{\frac{\partial EU}{\partial k}}{\frac{\partial EU}{\partial r}} = -\frac{\frac{\partial \mu}{\partial k} \left[\pi - (1+r) \left(k - \frac{\omega}{\lambda} \right) \right] - \mu(\theta, k)(1+r)}{\mu(\theta, k) \left(k - \frac{\omega}{\lambda} \right)}.$$

The expected profit reaches its highest level when the following relationship is verified:

$$\frac{\partial \mu}{\partial k_{t+1}} \left[\pi - (1+r_{t+1}) \left(k - \frac{\omega A_t}{A_{t+1}^{max}} \right) \right] = \mu(\theta_{t+1}, k_{t+1})(1+r_{t+1}) \quad (8)$$

The indifference curves increase according to the individual's ability since the rate of innovation increases with the level of knowledge of an individual; in other words, skilled agents are willing to accept high levels of interest rate on their loans because they have more chance to succeed their R&D activities and benefit high profits. Banks thus will offer a continuum of contracts according to the distribution of knowledge or ability.

Characterisation of the equilibrium: The national country's banks are supposed to be risk-neutral. Their resources come from the deposits of agents, at the rate R_{t+1} . For an investor who borrows $(k_{t+1} A_{t+1}^{max} - w_t)$, the banks earn an amount $(1+r_{t+1})(k_{t+1} A_{t+1}^{max} - \omega A_t)$ in the event of success of the research and development with a probability $\mu(\theta_{t+1}, k_{t+1})$ and have no profit in the case of failure with $(1 - \mu(\theta_{t+1}, k_{t+1}))$. In return, they pay to the lenders an amount equal to $(1+R_{t+1})(k_{t+1} A_{t+1}^{max} - \omega A_t)$. The expected mean outcome of a bank is:

$$E\Pi_{t+1} = \mu(\theta_{t+1}, k_{t+1})(1+r_{t+1})(k_{t+1} A_{t+1}^{max} - \omega A_t) - (1+R_{t+1})(k_{t+1} A_{t+1}^{max} - \omega A_t) \quad (9)$$

In equilibrium, the expected profit of a bank is null. The constraint of profitability of the banks is written as:

$$\mu(\theta_{t+1}, k_{t+1})(1+r_{t+1}) = 1+R_{t+1} \quad (10)$$

The iso-profit curves are convex in the plane (k, r) . Indeed, by noticing that the profit of the banks is null, $\mu(\theta_{t+1}, k_{t+1})(1+r_{t+1}) = 1+R_{t+1}$, we have

$$\frac{dr_{t+1}}{dk_{t+1}} = -\frac{(1+R_{t+1}) \frac{\partial \mu}{\partial k_{t+1}}}{[\mu(\theta_{t+1}, k_{t+1})]^2} \text{ and}$$

$$\frac{d^2 r_{t+1}}{d(k_{t+1})^2} = \left[\frac{1+R_{t+1}}{[\mu(\theta_{t+1}, k_{t+1})]^2} \frac{\partial^2 \mu}{\partial (k_{t+1})^2} - \frac{2(1+R_{t+1})}{[\mu(\theta_{t+1}, k_{t+1})]^3} \left(\frac{\partial \mu}{\partial k_{t+1}} \right)^2 \right] > 0.$$

The equilibrium financial contract of an agent is such that each bank announces its contract $(K_{t+1} - \omega A_t, r_{t+1})$ for a given level of knowledge θ_{t+1} and the borrowers simply select the preferred contract among the set of contracts offered by the banks. The level of credit of a borrower maximizes

her utility under the constraint of profitability of the banks. The agent of knowledge θ_{t+1} maximizes her utility under the constraint of profitability of a bank. The interest rate is not given a priori. The programme of the agent is summarised by the following system:

$$\begin{cases} \max_{\{r_{t+1}, k_{t+1}\}} \{\mu(\theta_{t+1}, k_{t+1})[\pi A_{t+1}^{max} - (1 + r_{t+1})(k_{t+1} A_{t+1}^{max} - \omega A_t)]\} \\ \text{st: } \mu(\theta_{t+1}, k_{t+1})(1 + r_{t+1}) = 1 + R_{t+1} \end{cases} \quad (11)$$

The equilibrium contract does not depend on the initial endowment of agents. The competitive equilibrium investment levels and interest rates verify:

$$\begin{cases} \pi \frac{\partial \mu}{\partial k}(\theta_{t+1}, k_{t+1}^*(\theta_{t+1})) = 1 + \hat{R}_{t+1} \\ \mu(\theta_{t+1}, k_{t+1}^*(\theta_{t+1}))(1 + \hat{r}_{t+1}(\theta_{t+1})) = 1 + \hat{R}_{t+1} \end{cases} \quad (12)$$

The investment levels in research and development are independent on the initial resources of the agents. The problem of an individual is really to determine which proportion of her initial wealth to allocate to R&D activities on the one hand and on the other hand which one to save on the capital market. Equation (12) then represents non-arbitration relation between saving and R&D investment. It indicates that the equilibrium investment level ensures the equality between the interest rate on loans and the gross expected marginal profit of R&D investment. The R&D investment level of an agent increases as she becomes richer. Equations (12) enable to express the interest rate on the credits and the investment levels as a function of ability and the interest rate on the deposits:

$$\begin{cases} k_{t+1} = k_{t+1}^*(\theta_{t+1}, \hat{R}_{t+1}) \\ r_{t+1} = \hat{r}_{t+1}(\theta_{t+1}, \hat{R}_{t+1}) \end{cases} \quad (13)$$

PROPOSITION 1

Let us suppose that the probability of innovation is $\mu(\theta_{t+1}, k) = B(\theta_{t+1})[1 - e^{-k}]$, with $0 \leq B(\theta_{t+1}) < 1$ and $B'(\theta_{t+1}) > 0$. Then the equilibrium R&D investment and interest rate on credits in perfect competition for a given ability and interest rate on deposits verify the following relations:

$$\begin{cases} k_{t+1}^*(\theta_{t+1}, \hat{R}_{t+1}) = \ln \left[\frac{\pi B(\theta_{t+1})}{1 + \hat{R}_{t+1}} \right] \\ \hat{r}_{t+1}(\theta_{t+1}, \hat{R}_{t+1}) = \frac{\pi(1 + \hat{R}_{t+1})}{\pi B(\theta_{t+1}) - (1 + \hat{R}_{t+1})} \end{cases} \quad (14)$$

Proof: When $\mu(\theta_{t+1}, k) = B(\theta_{t+1})[1 - e^{-k}]$, with $0 \leq B(\theta_{t+1}) < 1$ and $B'(\theta_{t+1})$, the relations (12) become:

$$\begin{cases} \pi B(\theta_{t+1})e^{-k_{t+1}} = 1 + \hat{R}_{t+1} \\ B(\theta_{t+1})(1 - e^{-k_{t+1}}) = 1 + \hat{R}_{t+1} \end{cases}$$

The result is straightforward.

The credit granted by the banks to an investor increases while the interest rate decreases as the level of human capital of an agent rises. Indeed, a qualified individual has a high probability of succeeding her R&D and of refunding the amount of her debt. On the other hand, it is more expensive for a less qualified individual to borrow from the banking system to invest in the R&D sectors, because she is unlikely to improve the quality of her intermediate good.

It finally remains to determine the equilibrium interest rate, $\hat{R}_{t+1}$, to clear the model. The following lemma defines the relationship between the R&D investment level and the human capital of an agent.

Lemma 1 *The equilibrium R&D investment of an agent increases with her ability.*

Proof: Let us consider the relation (12) and let us derivate. We have:

$$\pi \left[\frac{\partial^2 \mu(\theta_{t+1})}{\partial (k_{t+1})^2} dk_{t+1} + \frac{\partial^2 \mu}{\partial \theta \partial k_{t+1}} d\theta_{t+1} \right] = d\hat{R}_{t+1}.$$

Let us consider the assumptions on the rate of innovation, $\mu_{kk} = \frac{\partial^2 \mu}{\partial k^2} < 0$ and $\mu_{\theta k} = \frac{\partial^2 \mu}{\partial \theta \partial k} > 0$. The investment level increases with the ability when the equilibrium interest rate is carried out.

Lemma 1 clearly shows that if a set of agents are endowed with the same initial wealth then the decision of investment in the R&D sectors will be led by the innovation rate, in other words by the individuals' abilities.

When an individual invests a level of physical capital higher than the equilibrium R&D investment level, i.e. when there is over-investment, the expected marginal profit of the R&D investment is lower than the deposit rate. She must thus reduce her level of investment up to the equilibrium level and save the surplus of her first period income. Thus, an agent endowed with an income higher than the optimal level of R&D investment will self-finance her activities and becomes a lender. On the other hand, an agent having an income lower than the equilibrium level of investment in R&D will increase her level of investment while borrowing on the market of the capital.

PROPOSITION 2

Let us suppose that the probability of innovation is $\mu(\theta_{t+1}, k) = B(\theta_{t+1})[1 - e^{-k}]$, with $0 \leq B(\theta_{t+1}) < 1$ and $B'(\theta_{t+1}) > 0$. There is in the economy a threshold of ability, $\tilde{\theta}(\delta, \hat{R}_{t+1})$, depending on the technological backwardness and the deposit interest rate such that the individuals whose abilities are more important than this threshold are borrowers while the others are lenders. This threshold of ability verifies the equation

$$\ln \left[\frac{\pi B(\tilde{\theta})}{1 + \hat{R}_{t+1}} \right] = \frac{\omega A_t}{A_{t+1}^{max}}.$$

Proof: Lemma 1 has shown that optimal investment levels depending on individuals' abilities are continuous and strictly monotonic with abilities for all values in $[0, +\infty]$. Thus for a capital level equals to the wage $w_t = \omega A_t$, there is an ability threshold which allows distinguishing two types of individuals. Equation (12) thus states that skilled individuals are investors in the R&D sectors and the low-skilled are strictly lenders of funds on the capital market.

The previous proposition shows that in the economy, agents endowed with a low level of ability will be lenders while those who are more skilled will be borrowers. The lower is the national technology gap from the leading country the higher is the ability threshold $\tilde{\theta}(\delta, \hat{R}_{t+1})$ which discriminates the individuals.

The R&D investment depends on the ability and the endogenous interest rate. The interest rate, $\hat{R}_{t+1}$ on the deposits of the agents to the capital market is that which equalizes the aggregate capital demand $\int_{\tilde{\theta}}^1 \ln \left[\frac{\pi B(\tilde{\theta}_{t+1})}{1 + \hat{R}_{t+1}} \right] dF_{t+1}(\tilde{\theta})$ and the aggregate capital supply (or wealth ωA_t). is the distribution function of the ability level at $t + 1$. Let us denote by this distribution function at $t=0$. Thus, the series $\{F_{t+1}\}_{t=0,1,2,\dots}$ verifies the recurrence equation:

$$F_{t+1}(\theta) = F_t \left(\theta^\sigma \delta_t^{\frac{\sigma-1}{\sigma}} \right) \quad (15)$$

Lemma 2 The series $\{F_{t+1}\}_{t=0,1,2,\dots}$ increases for a given technology gap δ .

Proof: Human capital evolves according to equation (1). Knowing that F is the distribution function for ability, we have, for all $x \geq 0$:

$$F_{t+1}(x) = \text{Pr ob}[\theta_{t+1} < x] = \text{Pr ob}[\theta_t^\sigma \delta_t^{1-\sigma} < x].$$

$$\text{Finally, } F_{t+1}(x) = \text{Pr ob} \left[\theta_{t+1} < x^{\frac{1}{\sigma}} \delta_t^{\frac{\sigma-1}{\sigma}} \right].$$

The dynamics of the distribution function for human capital is expressed as $F_{t+1}(x) = F_t\left(x^{\frac{1}{\sigma}}\delta_t^{\frac{\sigma-1}{\sigma}}\right)$. Hence, the density function is $f_{t+1}(x) = \frac{1}{\sigma}x^{\frac{1}{\sigma}-1}\delta_t^{\frac{\sigma-1}{\sigma}}\frac{d}{dx}\left[F_t\left(\theta^{\frac{1}{\sigma}}\delta_t^{\frac{\sigma-1}{\sigma}}\right)\right]$ or $f_{t+1}(x) = \frac{1}{\sigma}x^{\frac{1}{\sigma}-1}\delta_t^{\frac{\sigma-1}{\sigma}}f_t\left(\theta^{\frac{1}{\sigma}}\delta_t^{\frac{\sigma-1}{\sigma}}\right)$. For a backward country, δ_t is less than one, and $\sigma < 1$, so $x^{\frac{1}{\sigma}}\delta_t^{\frac{\sigma-1}{\sigma}} > x$. Knowing that distribution functions increase, the series $\{F_{t+1}\}_{t=0,1,2,\dots}$ increases.

The equilibrium rate of interest $\hat{R}_{t+1}$ is solution to the following equation:

$$\omega A_t = \int_{\tilde{\theta}(\delta_t)}^1 \ln\left[\frac{\pi B(\tilde{\theta}_{t+1})}{1 + \hat{R}_{t+1}}\right] dE_{t+1} \quad (16)$$

To sum up, the set of contracts Ξ_{θ} suggested by the banks to borrowers is then given by:

$$\Xi_{\theta} = \left\{ \ln\left[\frac{\pi B(\theta_{t+1})}{1 + \hat{R}_{t+1}}\right] - \omega A_t; \frac{1 + \hat{R}_{t+1}}{\left(\theta_{t+1}, \ln\left[\frac{\pi B(\theta_{t+1})}{1 + \hat{R}_{t+1}}\right]\right)} - 1 : \hat{R}_{t+1} \text{ verifies (16), } \theta_{t+1} \geq \tilde{\theta}(\delta_t) \right\} \quad (17)$$

The lending rate of an agent is determined by the success probability of R&D activities and by the deposit interest rate. It is all the more weak as the agent is likely to innovate, i.e. when she is very skilled. The contract is Pareto optimal because it maximises both the utility of the borrowers and the profit of the banks.

Equilibrium contract with asymmetries: We suppose that individuals know their abilities perfectly. However, banks are unable to directly distinguish among borrowers of differing abilities, and accordingly the success probability of R&D. Moreover, they cannot learn the type of an agent. In other words, banks are uninformed about the ‘true’ ability of an agent. But banks know the distribution of human capital of agents as represented by Equation (15). They are able to observe ex post and without any cost whether the investment in R&D succeeds or fails. Hence, agents will always seek to borrow more than the first best amount of capital whatever their abilities. Banks offer an asymmetric information contract to these agents. As shown by Stiglitz and Weiss (1981) in their seminal work about credit rationing, banks making loans are concerned about the success probability of R&D, i.e. about the individual’s default risk. The interest rate a bank charges may itself enable to sort potential borrowers (adverse selection effect). Clearly, the interest rate which an individual is willing to pay may act as one such screening device: those who are willing to pay high interest rates may, on average, be worse risks; they are willing to borrow at high interest rates because they perceive their probability of repaying the loan to be low. Hence in the economy under asymmetries, as previously mentioned individuals endowed with ability higher than $\tilde{\theta}(\delta_t)$ can borrow and invest in R&D.

Banks are supposed to be risk-neutral. Hence knowing that the agents' levels of investment are given, banks will propose an interest rate on loans such that the equilibrium expected profit is null. The equilibrium rate of interest is solution of the following implicit equation:

$$\int_0^1 [\mu(\theta_{t+1}, k_{t+1})(1 + \bar{r}_{t+1})(k_{t+1}A_{t+1}^{max} - \omega A_t) - (1 + R_{t+1})(k_{t+1}A_{t+1}^{max} - \omega A_t)] dF_{t+1}(\theta) = 0.$$

Finally, the equilibrium rate of interest on loans verifies the banks participation constraint expressed as:

$$1 + \bar{r}_{t+1} = \frac{1 + \hat{R}_{t+1}}{\bar{\mu}} \quad (18)$$

where $\bar{\mu} = \int_0^1 [\mu(\theta_{t+1}, \bar{k}_{t+1}) dF_{t+1}(\theta)]$. Equation (18) is obtained using the independency between both random variables $(k_{t+1}A_{t+1}^{max} - \omega A_t)$ and $\{\mu(\theta_{t+1}, k_{t+1})(1 + \bar{r}_{t+1}) - (1 + R_{t+1})\}$.

Each borrower considers as given the interest rate on loans and maximizes the expected returns of her investment in R&D. Specifically, she resolves the following programme:

$$\max_{\{k_{t+1}\}} \{\mu(\theta_{t+1}, k_{t+1})[A_{t+1}^{max} - (1 + \bar{r}_{t+1})(k_{t+1}A_{t+1}^{max} - \omega A_t)]\} \quad (19)$$

Investment in R&D of the agent endowed with ability (or human capital) is solution to the following equation:

$$\frac{\partial \mu}{\partial \bar{k}_{t+1}} \pi A_{t+1}^{max} - (1 + \bar{r}_{t+1})(\bar{k}_{t+1}A_{t+1}^{max} - \omega A_t) - \mu(\theta_{t+1}, \bar{k}_{t+1})(1 + \bar{r}_{t+1})A_{t+1}^{max} = 0 \quad (20)$$

If the maximum utility value is achieved, that is equation (20) has a solution, then the equilibrium investment in R&D in limited information depends on the agent's human capital level and the interest rate on credits. Specifically, the investment level can be expressed as $\bar{k}_{t+1} = k_{t+1}(\theta_{t+1}, \bar{r}_{t+1})$. Else, if equation (20) has no solution, agents are constrained by the rate of interest. In this latter case, each agent investing in R&D declares to the bank her full information investment level, i.e. $\bar{k}_{t+1} = \bar{k}_{t+1}^*(\theta_{t+1}, \bar{r}_{t+1})$. The banks offer credit amounts to agents according to their participation constraint (18). The equilibrium contract under asymmetries is characterized by credit rationing. This result is summarized by the following proposition.

PROPOSITION 3

Let us suppose that the probability of innovation is $\mu(\theta_{t+1}, k_{t+1}) = B(\theta_{t+1})[1 - e^{-k}]$, with $0 \leq B(\theta_{t+1}) < 1$ and $B'(\theta_{t+1}) > 0$. Then equilibrium investment in R&D under asymmetries, $\bar{k}_{t+1} = k_{t+1}(\theta_{t+1}, \bar{r}_{t+1})$, verifies:

$$k_{t+1}(\theta_{t+1}, \bar{r}_{t+1}) = \ln \left[\frac{\pi B(\theta_{t+1})}{\bar{\mu}(1 + \bar{R}_{t+1})} \right] \quad (21)$$

The determination of the equilibrium contract in the case of asymmetries is different from that led out in the previous section where information about the agents' abilities is perfect. The clearing of the model is done by the interest rates on deposit and on credit, as expressed by equation (18). These two interest rates are fully determined by the aggregate supply-demand relationship and by the participation constraint of banks. Specifically, the deposit rate $\bar{R}_{t+1}$ and the lending rate $\bar{r}_{t+1}$ verify the following system:

$$\begin{cases} \omega A_t = \int_{\theta(\delta)}^1 \bar{K}_{t+1}(\theta_{t+1}, \bar{r}_{t+1}) dF_{t+1}(\theta) \\ (1 + \bar{r}_{t+1}) \int_0^1 [\mu(\theta_{t+1}, \bar{k}_{t+1}(\theta_{t+1}, \bar{r}_{t+1}))] dF_{t+1}(\theta) = 1 + \bar{R}_{t+1} \end{cases} \quad (22)$$

This system shows that, whatever the level of ability θ_{t+1} of an individual, banks will propose a constant interest rate $\bar{r}_{t+1}$ on credit amount. If the maximum profit of an investor is reached, the agent of ability $\theta_{t+1}(j)$ will declare to her bank the equilibrium investment level at the lending rate $\bar{r}_{t+1}$, as expressed by (22).

Ability thresholds and endogenous occupational choice: In this section, we aim at showing that in an economy with an imperfect capital sector; there are two thresholds of human capital which enable distinguishing of agents in terms of their occupations.

As previously studied, Lemma 1 has shown that the level of investment in R&D is an increasing function of the agents' level of human capital when capital markets are perfect. In this case, the lending rate decreases with the level of human capital of investors. However, when information on the capital markets is imperfect, the interest rate on lending is independent of knowledge. Hence, the following proposition evidences an upper-threshold of ability that enables determining the occupations of the agents.

PROPOSITION 4

There is a unique level of ability, defined by the relation such that:

$$\begin{cases} \forall \theta \in [\bar{\theta}, \bar{\theta}], \hat{r}_{t+1}(\bar{\theta}, \hat{R}_{t+1}) \geq \bar{r}_{t+1} \text{ and } K_{t+1}^*(\theta_{t+1}, \hat{R}_{t+1}) \geq K_{t+1}(\theta_{t+1}, \bar{r}_{t+1}) \\ \forall \theta \in [\bar{\theta}, \bar{\theta}], \hat{r}_{t+1}(\bar{\theta}, \hat{R}_{t+1}) < \bar{r}_{t+1} \text{ and } K_{t+1}^*(\theta_{t+1}, \hat{R}_{t+1}) > K_{t+1}(\theta_{t+1}, \bar{r}_{t+1}) \end{cases} \quad (23)$$

When the probability of innovation is, the upper-threshold of ability $\bar{\theta}$ verifies $B(\bar{\theta}) = \frac{1 + \bar{R}_{t+1}}{\pi} \left(1 + \frac{\pi}{1 + \bar{r}} \right)$.

It can be noted that the interest rate $\hat{r}_{t+1}(\bar{\theta}_{t+1}, \hat{R}_{t+1})$ is continuous and decreases with the level of ability θ_{t+1} . So the results of the previous

proposition are immediate. Hence, the thresholds $\tilde{\theta}$ and $\bar{\theta}$ allow to segment the capital markets.

Corollary 1: *When information in the capital market is imperfect, there are three types of agents who participate to this market:*

- i. The individuals endowed with a level of ability less than the lower-threshold are strictly lenders (Type 1);
- ii. The individuals endowed with a level of ability between the lower-threshold and the upper-threshold over-invest in R&D (Type 2);
- iii. The individuals endowed with a level of ability higher than the upper-threshold under-invest in R&D (Type 3).

Since talented borrowers have higher total and marginal returns in the successful state, they decide to invest a higher level in R&D. Due to asymmetries of information on capital markets the high-skilled agents (type 3) invest less than their first-best amount of investment in R&D while they have more chance to succeed their innovations. They are willing to increase their investment in R&D until both rates of return are equal. Because of the presence of moral hazard on agents, the interest rates paid by high-skilled are higher than that charged in full information. The agents of type 1 whose human capital is less than the lower-threshold $\tilde{\theta}$ have expected marginal profits lower than the lending rates of interest $\tilde{r}_{t+1}$ charged by the banks. Accordingly, they will not invest in R&D but will become lenders. The agents endowed with a level of ability between $\tilde{\theta}$ and $\bar{\theta}$ have expected marginal profits above the interest rate. They are willing to invest their first best amount of investment in R&D, but they borrow more to increase the chances to innovate since the lending rate is less than that of full information.

DYNAMICS OF THE TECHNOLOGICAL GAP

The level of productivity increases when the agents innovate in the economy. Hence the quality $A_t(j)$ of the intermediate good is replaced by the productivity level of the leading country, that is A_{t+I}^{max} . The country average productivity at date can be expressed as follows:

$$A_{t+I} = \int_0^{\tilde{\theta}(\delta)} A_t dF_{t+1}(\theta) + \int_{\tilde{\theta}(\delta)}^1 \mu(\theta, k_{t+1}) A_{t+I}^{max} dF_{t+1}(\theta) + \int_{\bar{\theta}(\delta)}^1 [1 - \mu(\theta, k_{t+1})] A_{t+I}^{max} dF_{t+1}(\theta) \quad (24)$$

Equation (24) can be rewritten as $A_{t+I}^{max} = A_t + (A_{t+I}^{max} - A_t) \int_{\tilde{\theta}(\delta)}^1 \mu(\theta, k_{t+1}) dF_{t+1}(\theta)$. We denote by the exogenous growth rate of the global technology of the

leading country and by $\delta_t = \frac{A_t}{A_t^{max}}$ the country's technology gap. δ_t is an inverse measure of the country's distance to the technological frontier. An increase in the technology gap means that the country's technology level converges toward the technological frontier. Consequently, the technology gap evolves according to:

$$(1 + g)\delta_{t+1} = (1 + g - \delta_t) \int_{\theta(\delta_t)}^1 \mu(\theta_{t+1}, k_{t+1}(\theta_{t+1}, r_{t+1})) dF_{t+1}(\theta) \quad (25)$$

Equation (25) is a convergence relation which states that convergence of the national country depends toward the technology leader on the human capital level, the distribution of human capital and the credits allocated to the agents for R&D activities. This result is in line of what has been shown out by Nelson and Phelps (1966) in their study on the role of human capital in the technological diffusion and in economic growth. In other words, a country encounters high growth rates if it invests in human capital and R&D activities for imitation or innovation.

CONCLUDING REMARKS

Technological progress is an important determinant for economic growth and convergence of less advanced economies. Far from the technological frontier, imitation of technologies is rather the main engine of economic growth.

In this paper, we argue that capital markets asymmetries lead to determine the occupational choices of the agents according to their abilities. This result is linked to the principal hypothesis, that is, agents inherit their parents' ability and the technique of production of the sector in which they have worked. Following Aghion et al., (2005), we build a two-period overlapping-generations model. Agents are supposed to be heterogeneous by the level of ability inherited from their parents. The first period income is endogenous and is devoted in second period of life either to savings or to investment in R&D. The endogenous model developed in this paper offers a theoretical framework to highlight the interaction between capital markets and the agents' occupations.

The occupational choice of an agent is determined by her level of human capital. We argue that asymmetries affect the structure of occupations of the agents of a country. More explicitly, because of capital market imperfections, agents can borrow only limited amounts for investment in R&D. Knowing that innovation success positively depends on the level of investment and ability, we show out the existence of two thresholds of ability which enable to distinguish three types of individuals, that are strictly lenders, implementers (or imitators) and innovators in R&D. Moreover,

imitation of technologies is led by the agents whose ability is more than the lower-threshold and R&D activities are undertaken by high-skilled agents who have higher chances to innovate. Accordingly, the pattern of occupational choice is determined by the probability of innovation.

Furthermore, we show that the economic growth rate and the national country's convergence towards the leading country depend both on the level and structure of human capital, and the amounts invested in R&D.

The model developed in this paper may be extended in several directions. From a theoretical point of view, the diffusion of technology is supposed to be exogenous. Indeed, technologically less developed countries undertake research and development (or imitation) according to the flows of ideas from the technology leader. Thus, a formalisation of the diffusion of technology (see for example Eaton and Kortum, 1994) will enrich modeling suggested. From an empirical point of view, the estimate of the distribution of human capital will enable to better characterise equilibriums and the long-term properties of the economy on the one hand, on the other hand simulations or econometric estimates will allow to better appreciate the influence of capital markets and human capital distribution on the economic growth rate and convergence of a backward country.

NOTES

- 1 They suppose indeed that the world is composed of m country to justify the existence of a technological frontier.
- 2 We suppose that the productivity levels are independent and identically distributed random variables. By applying the law of the large numbers, we have $A_t = E(A_t(j))$, where $E(\cdot)$ is the expectation operator.
- 3 It seems that there is in the economy a capital sub-market of each ability level θ_{t+1} .

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Building Systems of Innovation in an African Setting

The Cluster Initiative Development Approach

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SUMMARY

Under the current competitive environment the word 'innovation' has become catchy and the center of attention for both researchers and policy makers. Much of the academic discourse and policy targets are on how to spur innovative activities among national firms. Although the debate on factors facilitating innovative activities is far from being settled, it has concretely been established that innovation is systemic and context specific and therefore its facilitation requires multidimensional and context specific approaches. This paper proposes that innovation in the African context can best be built through cluster initiatives. In building the argument, the paper brings together literature on systems of innovation and those on clusters and argues that although the two concepts are means to the same end, they have taken rather parallel roots. It further argues that while the cluster concept is practical, the concept of systems of innovation is basically an *ex-post* rather than *ex-ante* concept, and therefore cannot easily be applied in building systems of innovation, especially in the African context. The Tanzanian Cluster Initiatives Project that has started showing positive results is used to back the theoretical arguments made in the paper.

INTRODUCTION

As the process of globalisation gathers momentum and competition among nations become fierce, the issues surrounding innovation are receiving ever-greater attention from both researchers and policy makers¹¹. This is from the fact that, innovation is considered as one of the most important competitive edges of nations. When it comes to competition, the issue is no longer price of goods and services, but quality. Much of the debate and

policy targets are on how to spur innovative activities among national firms. Although the debate on factors facilitating innovative activities is far from being settled, it has concretely been established that innovation is systemic and context specific, and therefore its facilitation requires multidimensional and context specific approaches. This paper is a modest attempt to propose how innovation systems can be built in an African context. It does this by bringing together cluster and innovation theories. In so doing, the paper revisits some theories on innovation and on clusters. The major objective is to attempt to bring the two together for better insights on how best to facilitate technological innovations in an African context. The paper proceeds to paint a rough picture of innovation systems of poor developing countries such as those in Africa; and then suggest cluster initiative approach as one of the best vehicles for initiating and nurturing innovative activities in Africa. This rather theoretical suggestion is backed by lessons learned as a result of pilot cluster initiatives project currently being implemented in Tanzania. Although the cluster initiatives are still at a very early stage, and not much in terms of economic gain is evident, early innovation indicators such as trust and linkage formation are already emerging. It is important to state outright that the major objective of this paper is not to propose concrete policy options for strengthening/building systems of innovation in an African context, but rather to instigate discourse on this very pertinent issue, especially the role of clusters in innovation systems development.

The rest of the paper is organised as follows: The next section presents a theoretical framework consisting of two strands of literature: those on innovation studies, and those on cluster studies. Section three is a brief recapitulation of an African setting as far as innovation system is concerned. The argument for cluster initiatives approach for nurturing innovation, especially for Africa is further emphasised here. Section four presents some lessons learned through the pilot project on cluster initiative in Tanzania; this section also introduces the concept of 'science parks' as a vehicle for introducing high tech based cluster initiatives. Finally section five draws some concluding remarks and makes some recommendations.

THEORETICAL FRAMEWORK

The theoretical framework proposed consists of two strands of literature: those on systems of innovation, and those on clusters. In concluding the section the two strands of literature are pulled together, to focus on how cluster initiatives approach is used to develop innovation system, especially for poor developing countries such as those in Africa.

THE CONCEPT OF TECHNOLOGICAL INNOVATION

The essence of innovation is novelty. It is both the process of introducing something new and useful and the new thing itself. It is a concept of very general application and there is a wide range of approaches to conceptualising innovation in the scholarly literature (Fagerberg et al., 2004). Innovation has also been studied in different contexts, including in relation to technology, social system, economic development, and policy construction. One can talk of innovation in education system, constitutional innovation, etc. This article is mainly concerned with innovation in economic context, defined as successful creation, development, and marketing of new goods or successful application of new techniques or ways of working that improve the effectiveness of an individual and organisation (Archibugi et al., 1994). Inbuilt in this definition are four major types of innovation: product innovation, process innovations, market innovation, and organisational innovation. Of the four types, product and process innovation are the most important. Non- technological innovation such as market and organisational innovation support product and process innovation (Teese, 1998; Lam, 2004).

Innovation can also be of differing degrees. It can be radical (completely new, but within the same techno-economic paradigm), and fundamental (completely new and cause a paradigm shift). An example of a fundamental innovation is the discovery of a transistor, which is the basis of the emergence of the IT industry. Innovation can also be incremental (small modifications of existing technology). Incremental innovations are achieved through learning by doing and learning by using (Rosenberg, 1982). According to Rosenberg (1982), the cumulative effects of these small changes can be as large and bring productivity growth that major innovations are capable of generating. It is a source of technological innovation that is not usually explicitly recognised as a component of the R&D process, which overlaps with the development and receives no direct expenditure as it does not involve major investment, which may be the reason why it is normally ignored.

DRIVERS OF INNOVATION AND THE ROLE OF CLUSTERS

This section will briefly discuss models of innovation and the concept of clusters independently. It then ventures into a rather more difficult task of bringing the two concepts together, highlighting the pros and cons of each; and finally concludes that, clusters, through cluster initiatives (CIs), is the best approach to build systems of innovation in an African setting.

Models of Innovation

Models or motive forces for innovation is a major area of concern for policy makers, and consequently has been, and still is, a major area of inquiry in academic discourse. The debate started with a linear model of innovation where innovations were thought to be triggered as a result of basic research in science resulting in a widespread marketing of new products and widespread use of new processes, and by implication economic growth (Coombs et al., 1987; Rosenberg, 1982). Science was thought to be an endless frontier; and all governments needed were a lot of scientists with well-equipped laboratories. This belief seems to have been instigated by the success of the Second World War military science, especially the Manhattan Project to develop the atomic bomb – the most destructive weapon ever made by a group of scientists and engineers, the first time in history. The Manhattan Project was a demonstration that scientific projects could be large, hierarchically organized and yet achieve pre-determined goals (Hallonsten, 2009). Later on, and as a consequence of the post war science, in 1945 Vannevar Bush – the then Director of the United States Federal Office of Scientific Research and Development – published a report; *Science, the Endless Frontier*, which laid the basic principles of the partnership between science and the state, and was incorporated in the American science policy as the document setting the course for the United States' development into scientific super power (Guston, 2000; Hallonsten, 2009).

However, as things unfolded in the North, especially after the military technology had trickled down to the civilian science and technology, the notion of linear model of the *push type* was criticised as being inadequate in explaining what was really happening, and the linear model of the pull type, where the market was considered to be decisive in making innovation happen, was introduced. The demand pull model emphasises the dynamics of market demand as the catalyst for technological change – the changing market potential guides innovative activities to most profitable areas (Schmookler, 1966). This model was again later on criticized as inadequate; leading to what was referred to as *interactive* model of innovation. It was argued that innovation happens as a result of complex interaction between the 'supply' (R&D labs, scientific and technical institutions) and the 'demand' (potential and actual users, and marketing organisations) (Rothwell and Zegveld, 1985; Lovio, 1985). This must have led to the birth of a more recent concept of National Systems of Innovation (NSI) which has become popular, and almost exclusively being used to analyse different innovation systems. Lundvall, a pioneer of the concept, defines *NSI as that system which is constituted by elements and relationships between those elements, which interact in the production, diffusion, and use of new and economically*

useful knowledge (Lundvall, 1992: 2). According to many proponents of NSI, the elements are largely of two types: organisations and institutions. Organisations are formal structures, where innovation-related activities take place. Some important organisations in the SI are companies, which can be producers, suppliers, customers, and competitors in relation to other companies; universities; R&D organisations; venture capital organisations and public innovation policy agencies. Institutions are a set of common habits, routines, established practices, rules or laws that regulate the relations and interaction between groups and organisations. The examples in the SI are for instance, incentive structures that influence innovative activities, patent laws and norms influencing the relations between universities and firms (Edquist, 1997). The concept of NSI, as observed by some scholars, cannot be generalised universally. It emphasises the specificity of innovative activities to a particular socio-economic and social-cultural context. Although the necessary types of organisations and institutions largely remain the same, their relative importance and the way they interact very much depend on the existing socio economic environment (Nelson, 1993; Lundvall, 1992; Gu, 1999; Edquist, 1997). Edquist (1997) also talk of the functions to be performed by the actors of the NSI. These are:

1. Provision of R&D and creating new knowledge.
2. Competence building (provision of education and training, creation of human capital, production and reproduction of skills, individual learning) in the labor force to be used in innovation and R&D activities.
3. Formation of new product markets.
4. Articulation of quality requirements emanating from the demand side with regard to new products.
5. Creating and changing organisations needed for the development of new fields of innovation, e.g. enhancing entrepreneurship to create new firms and entrepreneurship to diversify existing firms, creating new research organisations, policy agencies, etc.
6. Networking through markets and other mechanisms, including interactive learning between different organisations.
7. Provision (creation, change, abolition) of institutions, e.g. IPR laws, tax laws, environment and safety regulations, R&D investment routines, etc. that influence innovating organisations and innovation process by providing incentives or removing obstacles to innovation.
8. Incubating activities, e.g. providing access to facilities, administrative support, etc. for new innovating efforts.
9. Financing of innovation process and other activities that can facilitate commercialisation of knowledge and its adoption.

10. Provision of consultancy services of relevance for innovation process, e.g. technology transfer, commercial information and legal advice.

The above ten functions can selectively be applied in building systems of innovation depending on the context and extent to which the system has been developed. The functions are especially important in identifying gaps in the required organisations and institutions for a certain system of innovation to perform well. We will return to this point when discussing how cluster initiatives are used to build systems of innovation.

As earlier explained, the above developments in the theories and policies on technological innovation to a large extent were based on the empirical observations of the changes in practice; in the now developed countries – *academic discourse and policies chased practice* while, as we shall see shortly, in most African countries such as Tanzania, policies are chasing theories developed from the empirical observation based on very different contexts. Worse still, the theories claimed to have become redundant in the context in which they originated. A good example is the over-emphasis on scientific research and training of more scientists as a way of fixing the African technological problem. This practice seems to be rooted in the Bush report alluded to above, which has already been overtaken by events. This is ironic because it is well known that the greatest technological problem in Africa is the link between science and the technology, and not the inadequacy in scientific research.

The Concept of Clusters

Clusters are groups of firms engaged in similar or related economic activities in a national economy. In most cases they are defined by two important attributes, namely spatial agglomeration and sectoral dimension. According to Rosenfeld (1997), cited in Le Veen (1998), an industry cluster is a geographically bounded concentration of similar, related or complementary businesses, with active channels for business transactions, communications, and that are faced with common opportunities and threats. According to Porter (1990), clusters are basically of two types: horizontal and vertical. Vertical clusters are made up of firms that are linked through buyer-seller relationships. Horizontal clusters include firms that share common market for the end products, use common technology or labor force skills or require similar natural resources; they are basically competitors. However, in most cases clusters are made up of both horizontal and vertical relationships. In short they are firms, their suppliers, users and competitors co-located geographically. Clusters have, in most cases, been associated with dynamism, innovation and competitiveness, basically because of collective

efficiency, linkages and externalities that enable enterprises to overcome many constraints in the area of capital, skills, technology, markets, etc. Three advantages of firms locating in clusters can be identified in the literature. The first advantage is the intensity of a labor pool due to geographical concentration of firms in the same industry or in closely related ones. The second advantage is the availability of related materials and other inputs at lower costs. These inputs include tangibles like raw materials and supplies, and intangibles like consultation and collaboration. The third advantage is the intensity of knowledge exchange that can lead to knowledge spillovers between nearby firms and institutions in the cluster (David et al., 1990; Krugman, 1991; Kelly et al., 1999; Oyeyinka, et al., 2007).

Whereas all clusters, as indicated above, may have properties that serve to speed innovation, some can be observed to be particularly prone to innovation (Anderson et al., 2004). This has led to the coining of the concept of *innovative clusters*. An innovative cluster innovates in the broadest sense of the concept as earlier discussed. That is, innovation can emanate from improvements in the way that actors organise themselves; new products are developed, produced, commercialized and distributed. An innovative cluster is, in principle, evolving constantly, learning from experiences and able to adjust to changing circumstances. It is likely to be well positioned to explore new opportunities beyond its present boundaries and at the same time, combine flexibility with inner strengths, stability and sense of direction to achieve the following:

- Traditional boundaries to knowledge generation and diffusion are continuously changed by establishing linkage to wider and alternative sets of knowledge inputs.
- Products and markets are re-conceptualised.
- Mechanisms for seed-funding, risk-taking and entrepreneurship are upgraded.
- Old institutions and organisations are transformed through learning as well as unlearning of earlier habits and practices (Anderson et al., 2004).

The above transformations can be aided through cluster initiative development, the subject we will shortly return to.

(a) Clusters and Systems of Innovation

The concept of clusters and systems of innovation are somehow related; and perhaps are means to the same end, which is competitiveness. However scholars of the two concepts have stressed two different things in the same value chain. While scholars of clusters have stressed competitiveness

directly and rarely mention innovation explicitly, scholars of innovation systems have stressed innovation as a means to achieve competitiveness; and therefore the major focus has always been innovation and how best to nurture it. In terms of effectiveness in facilitating competitiveness, the two concepts have pros and cons. The cluster concept is much narrower than the innovation system. It explains, and can be used to facilitate innovative activities at a micro level, while innovation system takes into account circumstances and institutions at a more macro level. However, while the concept of systems of innovation is so rich in explaining circumstances and conditions under which innovation can occur so that nothing is omitted in trying to put a jigsaw-puzzle of innovation together, the concept is so loose to the extent that its proponents have failed to pin it down in terms of how to use it to facilitate innovative activities. Some of these weaknesses have been acknowledged by its pioneers. For instance Lundvaal et al., (2002: 226) acknowledge that the concept has not yet been applied to system building – it has mainly been used as an *ex-post* rather than *ex-ante* concept. To the contrary, the concept of clusters has been, as we will shortly see, operationalized through cluster initiatives; and experience has shown that it works.

In concluding this section, it suffices to say that *innovative cluster* can be equated to the well performing *systems of innovation*, especially at the micro and local levels. We have also mentioned that, while there are not yet any concrete practical ways to facilitate innovative activities using the concept of systems of innovation, there are practical ways that have been proposed to achieve innovation through the concept of cluster initiatives. The following section discusses issues surrounding this concept. Major emerging issues will be used to explain early success stories in the Tanzanian cluster initiative project.

DEVELOPMENT OF CLUSTER INITIATIVES OR BUILDING SYSTEMS OF INNOVATION

As earlier alluded to, many clusters evolve spontaneously and take shape gradually over an extended period of time. The process falls into 4 main phases: (i) creating trust; (ii) forming linkages; (iii) vision or strategic direction; and (iv) undertaking actions (Anderson et al., 2004). However, recently, there has been a wide spread practice in externally intervening in this otherwise natural process. This conscious external intervention is popularly known as *cluster initiative*. The interventions are geared towards speeding up the process of a development of a cluster, or preventing it from stagnation and decay. Generally, the process is intended to instill dynamism in a cluster and make it more innovative and competitive. Various actors who relate to each other in different ways carry out the intervention. Governments and other public authorities are known to be responsible for

most cluster initiatives, although there are marked geographical variations. For example in the US the private initiatives are more common (Solvell et al., 2003, cited in Anderson et al., 2004). However, even if the initiative is started by a non-government entity, to a large extent the initiative will still depend on the government in terms of provision of funds and other incentive structures. The government is therefore a very important agent in cluster initiatives.

This article argues that, by analogy, cluster initiatives development can also be termed as building systems of innovation at the micro level. The cluster initiative, or system of innovation development can start at any given phase of the naturally developing cluster; and in the literature there is no one fit approach to trigger the process. There are however three major alternative cluster initiative processes: (i) the engineered; (ii) the organic; and (iii) the re-engineered. Each goes through the same general phases mentioned above, but with different entry points according to the stage at which the cluster is at the time of intervention. It is very important to recognise the phase at which a certain cluster is at the time of intervention as this gives a rough idea – with the assistance of the ten functions of systems of innovation earlier mentioned – of what activities to start with, and what new organisations and institutions need to be put in place. Below we discuss different cluster initiative processes and their entry points.

The Engineered

This is generally a top-down cluster initiative approach. It is typical of those clusters that are still at the early stage of development. In Europe, policy makers lead and in North America, it is the private individuals who are important. In Africa who leads or rather who can lead? University? NGOs? Development Partners? The answer to this question is not yet apparent at this point in time as cluster initiatives is a very new concept in Africa. However, as earlier alluded to, and as will shortly be evident through Tanzanian cluster initiatives pilot project, government is a very important actor. While cluster initiatives can be started by any of the above mentioned actors, for sustained interventions and growth the government has to come in, in one way or the other.

The initial catalyst of an engineered cluster process could be a given investment opportunity, a dynamic leader, or a regional/national economic crisis (poverty for Africa). The general steps are as follows:

- Form or develop existing social capital to anchor the cluster idea.
- Maintain or establish new mechanisms for building trust, formulate a vision and strategy and then undertake action.

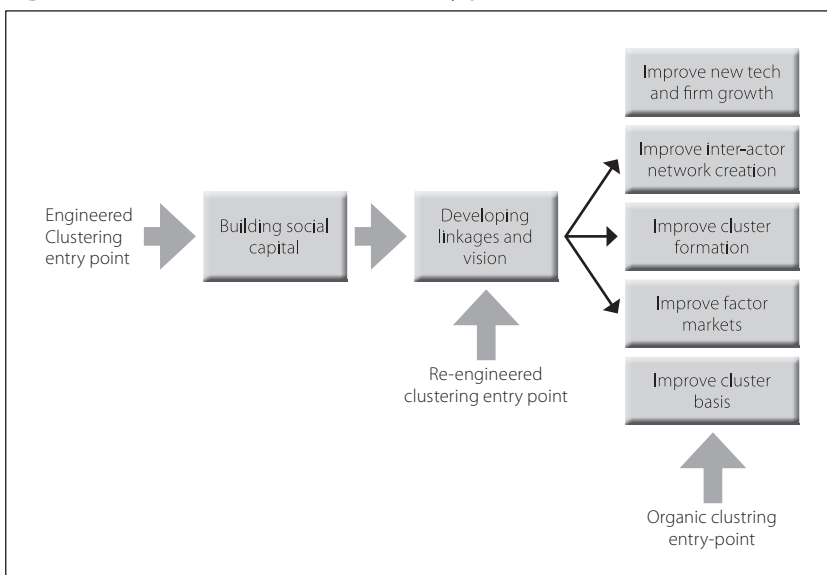
The Organic

This is a bottom-up approach. These clusters initially display spontaneous development towards the establishment of linkages and joint strategy. From this platform of continuous or recurring instance of cooperatives, an innovative cluster appears. Intervention or cluster initiative is targeted at the tightening of networks and collaboration, introduction of supportive framework, acquisition of things such as new technology, and removal of rigidities.

The Re-engineered

The re-engineered cluster is when an existing cluster (engineered or organically developed) is viewed as having specific competitive significance or potential, but is hindered from progress for some critical reasons. Key linkages are broken or never formed, or there are other crucial delimiting factors within the cluster itself or its surrounding that are blocking its dynamism. For such reasons the process is re-started through corrective actions such as re-establishing, or establishing key linkages, dismantling or breaking of adverse rigidities; or through the communication of new vision and strategy. The whole picture of these processes with different entry points can be represented diagrammatically as shown in Figure 1 below. The figure is very useful in indicating entry points for external intervention for clusters at different stages of natural development.

Figure 1 Cluster initiatives different entry points



Source Adapted from Anderson et al., (2004).

As earlier discussed, innovation is context specific; therefore before we put forward our argument that cluster initiatives development is the most efficient way of building systems in Africa, we will discuss, albeit briefly, the African context within which the innovation system is placed.

SYSTEM OF INNOVATION IN AN AFRICAN CONTEXT: THE REALITY

There are debates in the literature on whether or not anything like systems of innovation exists in the least developed countries. The debate seems to be in favour of our contention that as long as some form of innovation exists in the least developed countries, then some form of a system of innovation must exist (see for instance, Lundvall et al., 2002). The real disadvantage of Africa in this is the lack of systematic studies on innovation in the context of Africa.

Having said the above, the real intention of this section is not to discuss innovation systems in an African setting, but rather, as mentioned above, to discuss the context in which innovation systems are placed. African context is characterised by two major system weaknesses that have a direct bearing on the most basic forces behind innovative activities, i.e. *technology push* and *demand-pull*. Briefly, the first weakness is that African economies are very fragile, the markets are small and underdeveloped. While to a large extent, consumers in more developed countries can express their needs through clear-cut market mechanisms, those in most African countries are not empowered to do so. This disempowerment largely manifests in low level of education of the populace and low per capita income, which are the two most important aspects in empowering people to demand innovative products. In addition, infrastructure, especially those related to communications, are weak, R&D are not conducted in firms, but public organisations and largely divorced from the productive sector (Wangwe et al., 1998); and there is lack of venture capital organisations.

The second important weakness is a conspicuous disconnect between science and technology in most African countries. It is important to note that there are currently radical global developments taking place in the field of science and technology. There is ever increasing convergence between science and technology. In the sense that the line between the two has become extraordinarily thin – science is increasingly becoming technology and technology becoming science. Good examples are fields of biotechnology and nanotechnology. This is not a problem for the developed countries because science and technology are more or less intertwined – it is where the convergence between science and technology is currently happening. The situation in Africa is different. While the scientific community in Africa to a large extent is moving ahead with the rest of the scientific community globally¹², technology in Africa has to a large extent remained local, and

at a much lower level and divorced from science. But to avoid long-term or permanent marginalisation under increasing globalization, Africa must endeavor to build organic relationship between science and local technology.

Apart from the above mentioned weaknesses, the African environment is different in the sense that it consist of many diverse subsystems such as an agricultural sector (food and cash crops) and an industrial sector that largely consists of manufacturing and mining. Within the industrial sector, there are also large and small-scale enterprises, which are both formal and informal. In short African innovation systems consist of many different sub-systems, with different actors, problems and challenges, hence requiring a different set of policies to facilitate innovative activities. For these reasons, it is much easier to facilitate and manage innovation at a more micro level depending on the above different contexts. For this reason, in an attempt to build systems of innovation in an African setting, we recognise the special relevance and importance of cluster initiatives, especially the innovation enhancing aspect of clustering¹³. Clusters are especially important vehicles for the African setting for the following reasons: First, is the already discussed fact that the concept of systems of innovation is a bit abstract and vague, and difficult to operationalise, especially in an African context, where there are diverse sub-systems; second, projects draw attention of the governments and donors for some practical actions. If it goes in the name of a cluster initiative project, innovation system building will have a better chance of succeeding than general innovation policies that are normally not backed by systematic empirical studies of the African situation. Moreover, most policies in Africa lack implementation strategies. A cluster initiative approach will enable Africa to move beyond the meaning of policy as simply *nicely packaged blue prints to a course of action*, where lessons that emerge as clusters evolve are continuously being incorporated into the cluster policies. The ten functions of systems of innovation earlier alluded to can help in putting in place missing institutions and organisations as clusters grow towards maturity. Lastly, the initiative can be started by any body as a demonstration to attract the attention of those who matter, just as it was done by the College of Engineering and Technology of the University of Dar Es Salaam but managed to attract the attention of the government and development partners.

SOME LESSONS FROM A PILOT PROJECT ON CLUSTER INITIATIVES IN TANZANIA

In this section we make reference to the ongoing cluster initiatives project in Tanzania. The section also proposes a methodology of initiating high tech clusters.

THE CURRENT PROJECT

Tanzania embarked on the cluster initiatives project in early 2006 through the generous support of SIDA. During the 18 months of the pilot project, 8 clusters were selected for the cluster initiatives. These clusters are: Metalworking and Engineering Cluster, Mushroom Cluster, Vegetable Seed Cluster, Seaweed Cluster, Tourism and Cultural Heritage Cluster, Nutraceuticals Cluster, Sisal Cluster, and Vegetable and Fruits Cluster. The project started with the training of the cluster facilitators on the cluster initiative concept and the identification of 'low hanging fruits'; that is, identification of the immediate needs with lowest cost possible by the cluster facilitators. The progress of the eight clusters was monitored over the 18 months life of the project. At the end of the 18 months, the project was evaluated; and four clusters were chosen for upgrading. This paper draws lessons from this final evaluation to argue the case for emerging innovation systems¹⁴. Although it is too early to draw any conclusion, the project seems to have put the participating actors on the right path towards stronger innovation systems with a potential to develop much stronger in future. As earlier alluded to, clusters evolve and take shape gradually over an extended period of time.

Important lessons learnt during the project evaluation include the increased visibility of actors, trust and linkage formation, collective efficiency and product diversification. It is important to note here that, as already discussed; these factors are at the core of the innovation capability building. The following paragraphs explain each of these:

Visibility

The project has been instrumental in popularising the cluster concept, and in increasing the visibility of firms and farms in the project, and has succeeded in drawing the attention of government officials and donors. As a result, some clusters have already received some assistance from government agencies with some positive impacts. A good case is the mushroom cluster where the cluster accessed a building to act as a mushroom collection center from the local government. This cluster also accessed funds for training and production of the mushroom growers' manual from the Small and Medium Enterprises (SME) Competitiveness facility. The Morogoro Food processing cluster acquired a premise for a joint market outlet from the local government in Morogoro region. Even though, the assistance has not been much, and tangible economic gains are less visible at this point in time, social and political capital cultivated so far promise to be of great value in the future.

Trust and Linkage formation

Trust and linkage among firms and farms in clusters are the greatest capital for innovation and prosperity. It is encouraging to see that the project has achieved a noticeable level of trust and linkages among cluster members. In the words of one cluster member of the mushroom cluster during one of the focus group discussions:

Not only has our business relations improved, but also our social life. It was not common for me to talk to some of the cluster members, not even to exchange greetings, but now we are buddies, and I feel free to confront them with whatsoever problem I have, whether social or business.

This seems to be a sentiment shared by most of the cluster members in all the eight clusters. For clusters such as mushroom and seaweeds farming, where the business is so knowledge intensive that a small mistake can ruin the whole business, clusters have most visible impacts on the improvement of the products' quality because of enhanced sharing of information and learning from each other. Through linkage and learning, the banana farmers also gained more income by discovering that banana leaves are used in mushroom farming. The Morogoro Food processing cluster has now a joint marketing outlet for their products, which is a better marketing strategy, especially for small producers.

In the case of the Morogoro metal cluster, there is now an improved cooperation between the cluster members, especially between the small and larger firms. In the words of one cluster member, before the project, it was unthinkable for small entrepreneurs to approach the larger firms for help, but now it is much easier. Generally the incidence of cooperation such as joint purchases of inputs and job sharing in cases where orders go beyond individual capacity has increased among cluster members. There has also been some technology transfer, in terms of training as a result of the project, and the sharing of information among the cluster members.

The cluster initiatives project has enhanced linkage with the higher learning institutions for some clusters, even though there is mixed feelings in this. While some clusters are happy with the assistance they receive from the university, others complain that equipment from the university is more expensive and not necessarily superior to same equipment from elsewhere in the country. This complaint has also been observed by a study on public perception of the roles of universities in socioeconomic development in Tanzania (Mwamila and Diyamett, 2009). This point to the importance of the relationship between science and technology earlier alluded to.

Collective efficiency

Another important attribute of a cluster is collective efficiency, which reduces the cost of doing business, and also leads to innovative activities especially in subcontracting and collective branding. This is already happening with some clusters in Tanzania. The existing collective efficiency is in the form of a joint market outlet (Morogoro Vegetable and Fruits, and Mushroom); joint purchase of raw materials (Morogoro Metal Work); job sharing and subcontracting (Morogoro Metal Work); joint exhibition (Morogoro Metal Work, Mushroom and Morogoro Vegetable and Fruits) and collective branding, which is in the process (Morogoro Vegetable and Fruits cluster).

Product Diversification and Quality Improvement

The cluster initiative project has led to an increased product diversification and increased value chain in some clusters. Good examples are mushroom and seaweed clusters. For mushroom cluster for instance, new mushroom products such as cakes and other snacks have been developed by the clusters. This is the result of training, and information sharing among cluster members. For the seaweed cluster, the project has led to improved quality of seaweed, which stems from the introduction of appropriate drying techniques: Before the cluster initiative, farmers used to dry seaweeds by spreading them on the ground to be sun-dried, and in the process they collected dirt. Through the cluster initiative project farmers were introduced to new drying techniques whereby seaweed contamination with dirt is avoided. This has the potential of raising prices. The project has also introduced deep water farming where floating raft techniques are used. This has contributed to product quality improvement. The cluster is also moving towards high value addition activities. Traditionally, in Tanzania, seaweeds are farmed, harvested, dried and sold to traders ready for export. One of the positive achievements of the cluster is the ongoing efforts to add value by diversifying its local use. Though still work-in-progress, the proposed products include seaweed herbal soap products and seaweed snacks.

INITIATING HIGH TECH CLUSTERS

We earlier on argued that the Tanzanian systems of innovation, among others, consist of low tech sub-systems where innovation is incremental and achieved through learning by doing, rather than from R&D per se. This, to a large extent, is the case for all clusters in the above cluster initiatives projects. Although the cluster initiative project is being coordinated from the College of Engineering and Technology (CoET), University of Dar es Salaam, none of

the clusters is a result of a commercialisation of the research output from the University. However, there is the possibility for the university research output to come in as clusters move up the value chain, especially for the mushroom and seaweed clusters where there is clear indication of these clusters moving up the value chain. Otherwise the practice perpetuates the traditional de-link between science and technology that exists in most African countries. This article argues that there is also a need to venture into cluster initiatives that will endeavour into the commercialisation of new ideas emanating from the scientific research carried out by universities, especially for the cluster initiatives initiated and coordinated by a university such as this one. There are two major reasons for this: First, this is important if Africa is to be an equal player in the ongoing process of globalisation. Second, commercialisation of scientific research is important for closing the gap that exists between science and local technology. The gap does not only have serious implications for the country's socioeconomic development, but can also actually hamper scientific progress in the country. As earlier discussed, science and technology are interdependent, and science can only grow if it is put into practical application. From time in memorial, science and technology (S&T) have been influencing and benefited from each other. This is the reason S and T have always appeared together. In the early days, technology was a leader and science a follower. An example is the steam engine that was developed without any known scientific principle. On the other hand, the laws (science) of thermodynamics were discovered as a result of learning the working of the steam engine. Of course later on science became the leader and technology very much benefited from science. For this reason, if the organic relationship between science and local technology in Africa is not forged, to a large extent the direction of growth of science in Africa can be influenced by what is practical in developed countries. This is based on the fact that, as earlier alluded to, scientists in Africa collaborate more with scientists in developed countries than they do with peers within Africa; and we have already argued that science and technology are more or less intertwined in developed countries.

Having said the above, the intention of the article is not to suggest concrete modalities of putting the cutting edge science in Africa into practical application, but rather to point out that this is an important research and policy gap in the Tanzanian systems of innovation, and to stimulate debate on the issue. This notwithstanding, the article will attempt to point out two major generalities on the issue. The first is on the approach and the second is on priority areas.

One of the best approaches in creating a linkage between cutting age science and technology is through the concept of science parks. This is one form of a cluster initiative, which normally involves high technology companies. A Science Park consists of a space and buildings, normally close to a center of knowledge generation, such as the university. The structure, role, and

positioning of a science park in a country's science, technology and innovation system very much depends on the social and economic environments of that particular country. In most cases a science park will consist of university and other public centers' research groups; R&D units of companies; new spin off companies from universities, and new start-up companies from the existing business. All these in a space provided with top facilities to develop scientific and business activities. The major objectives of science parks include:

- Promoting R&D by the university in partnership with industry
- Assisting in the growth of new ventures
- Providing an environment where knowledge-based enterprises can develop in close interaction with a center of knowledge for their mutual benefit (UNESCO, 2007).

In terms of priority areas of investment for the Tanzanian environment, pharmaceuticals, agro-processing, mining and energy sectors could be chosen. These sectors have been chosen because the country has a comparative advantage in terms of the availability of natural resources, and they could also have profound impact on poverty reduction and growth strategies. The starting point could be to put in place a center for research commercialisation within the university, where the first activities of this center can be analysing all the university research outputs with the objective of identifying those with commercial potential.

SOME CONCLUDING REMARKS AND RECOMMENDATIONS

This paper has argued that the cluster initiative approach is the best available means of building systems of innovation in an African setting. Clusters have, in most cases, been associated with dynamism, innovation and competitiveness, basically because of collective efficiency, linkages and externalities that enable enterprises to overcome many constraints in the area of capital, skills, technology and markets. These are precisely the attributes of a strong innovation system. However, while cluster theories have elsewhere been put in practice, and seem to be working, the concept of the system of innovation so far has only been used to explain and not to build systems of innovation – it is an *ex-post* rather than an *ex-ante* concept. This is, but one reason for proposing a cluster approach for building systems of innovation in Africa. Another important reason is that African systems consist of diverse sub-systems, making it more suitable for the use of micro approaches, where cluster initiatives fit better than policies for the development of system of innovation, which is normally applied at a more macro level.

However, although the project is being coordinated from the University, none of the clusters is the result of the commercialisation of the university research. This practice perpetuates the traditional de-link between science and technology. However for Africa to avoid marginalisation and join the global value chain in production and marketing of products, it has to start investing in the commercialisation of its research outputs. Three important actors have a role to play here. These are universities, governments and the private sector. Universities, especially through spin-off companies, have the upper hand here. Universities have to conceive strategies to commercialise their potential research results. Universities, especially the faculties of science and engineering, in collaboration with the faculties of commerce and economics should join hands to commercialise their research results. This however is not to argue that universities should work in isolation, but rather to argue that universities need to be proactive and sensitise the governments and the private sector on the need and potentials of commercializing research results emanating from their labs. Universities can demonstrate the viability of commercialising research results by starting spin-off companies; and governments have a very important role of putting in place incentive structures, including provision of venture capital.

Finally, we make three major proposals: two on policy implications and one in the area of further research. On policy, there is a need to encourage cluster initiatives in two distinct areas: First is the low technology sub-systems, where innovation is largely incremental, and achieved through learning by doing. These clusters can be managed by many other different bodies in the country such as public research institutions, commissions or councils of science and technology, and other relevant ministries. Second is the high tech innovation sub-system where scientific research emanating from universities and other similar institutions of higher learning are commercialised. These have to be managed by the universities themselves. In this regard the concept of science parks that is increasingly being referred to in Africa must now start taking shape.

The final proposal is on areas for further research. In this regard we propose that academic discourse on innovation and Africa should think outside the current *systems of innovation* box that has been developed in the context of the mainly developed countries.

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Are North–South Technological Spillovers Substantial?

A dynamic panel data model estimation

Watu Wamae

SUMMARY

This article argues that *actual* technological spillovers are not substantial in developing countries because of the weak absorptive capacities. A panel data analysis is used in an attempt to gain insight into the specific aspects that enable economies to benefit from the backlog of existing knowledge. The findings indicate that low productivity effects of human capital coupled with weak or virtually non-existent systems of innovation are at the root of the observed ambiguity with regard to the spillover gains that are expected to play a significant role in sparking growth.

INTRODUCTION

Among developing countries, there is a growing rift between the few economies that have managed to ‘take-off’ and the overwhelming majority that is increasingly being marginalised by the current economic trend of rapid transformations. From a more general perspective, there is a great deal of evidence against the inevitable convergence predicted by earlier models, such as Solow (1956). Temple (1999:151) points out that, ‘Poor countries are not catching up with the rich, and to some extent the international income distribution is becoming polarized.’ This situation has arisen with technology taking the centre stage in driving economies and modifying dynamics in the global economy. The question addressed in this paper is: What lies behind the ability of a handful of developing countries to catch up with industrialised countries while the vast majority recedes further into marginalisation?

Technology-led growth is characterised by rapid changes, due to pressure from such factors as rapid technical change and liberalisation, and

evidence suggests that the returns to human capital are increasing, resulting in skill-biased technical change. However, the primary focus of classical, neoclassical and endogenous growth theory remains the allocation of scarce resources; structural feedback mechanisms that determine the dynamism of linkages and synergies in a rapidly changing environment are not taken into account. The national systems of innovation is an alternative approach proposed within the evolutionary technical change framework.

Pioneered and elaborated by Nelson and Winter (1982), Rosenberg (1983), Freeman (1987) among others, the national systems of innovation approach emphasises that the innovation process is a process of interactive learning in which actors improve their competences.¹ The endogenous structural, institutional and social factors, which constitute the so-called technological gap, have been stressed within the systems of innovation approach as largely responsible for driving economies apart. The underlying fact is that rapid economic transformations render competence acquisition increasingly tacit, and hence the importance of an adequate system of networks and linkages between and among actors and institutions.

This article attempts to show how the wide divergence among economies is mirrored by the rate of growth of knowledge, and that it reflects structural, institutional and social factors. More specifically, it is argued that domestic innovation in developing countries is a vital source of sustainable growth despite the popular view that importing high technology equipment is the best way or even the only way to ignite growth in developing countries, and especially in the poorest, since they seldom invest in domestic R&D and innovation systems. Domestic innovation creates domestic technological capacities and capabilities. This increases the potential for technical progress through the interdependent process of domestic knowledge creation and the development of an absorptive capacity: the economic dynamism created by local innovation forms the basis for knowledge assimilation without which foreign technology cannot be absorbed and successful take-off that leads to catching up cannot take place.

The argument is supported by the observations made by economists of technical change regarding the dual role of innovative activities. For example, Cohen and Levinthal (1989:569) argue that 'while R&D obviously generates innovations, it also develops the firm's ability to identify, assimilate, and exploit knowledge from the environment.' They further qualify this argument and postulate that 'firms may conduct basic research less for particular results than to be able to provide themselves with the general background knowledge that would permit them to exploit rapidly useful scientific and technological knowledge...', Cohen and Levinthal (1990:148). Basic research broadens the knowledge base to create a critical overlap with new knowledge. In a similar vein, Abramovitz (1986) suggests that

technical congruence is one of the elements that supports the capacity of followers to exploit existing knowledge.

Foreign R&D is often considered as the main means of acquiring technology, and an analysis of north-south spillovers has led to a heated debate. Substantial economic literature propounds that technological growth in developing countries depends on foreign technology acquired through international transfer of technology, and as a result technology diffuses from the north to the south resulting in a reduction of the technology gap over time. For example, Coe et al., (1997) empirically examine the extent to which developing countries, which hardly invest in their own R&D, benefit from R&D performed in industrialised countries, and conclude that spillovers from the north to the south are substantial. Such contentions have been met with resistance in view of the fact that foreign R&D cannot on its own revamp systems of innovation: it appears unlikely that foreign technology may have much impact in the absence of an absorptive capacity. Indeed, the capacity to benefit from foreign technology appears to depend on the systems of innovation whose development relies largely on domestic innovation rather than on foreign technology.

An avalanche of empirical studies indicating that technology diffusion from industrialised countries has stronger effects in relatively rich countries than in poorer ones reinforces this point (e.g. Eaton and Kortum, 1996; Xu, 2000; Keller, 2001). It is more probable that development of an absorptive capacity – which implies the need to focus on investment in domestic R&D, and human capital development as well as reinforcement of networks and linkages in the case of poorer developing countries – is paramount for productivity growth. The paper shows that domestic innovation lies at the core of the technology gap and is key to shrinking income differences over time.

Traditionally the concept of absorptive capacity has been associated with R&D activities in firms. Recent literature has extended it to relate to competence building in a rapidly changing economy as well as to include larger entities such as industrial districts, countries and regions. It is noteworthy that innovation arising from R&D is not the autonomous determinant of technical change: incremental transformations are responsible for the bulk of technological knowledge. In the analysis, domestic innovation in developing countries specifically relates to innovative activities based mainly on incremental knowledge. The paper defines variables that relate to innovative activities, and in particular to technological knowledge dynamism at an economy level and then analyses their trends across groups of developing countries. The aim is to map out countries' ability to establish technological learning systems, and hence, to create technological knowledge that leads to technical progress.

The approach that is used consists of viewing total factor productivity as a residual in the production function. The residual is obtained by computing the ratio of national income to factors of production in a model that relates output to factor inputs, and a relationship between total factor productivity growth and both domestic and foreign knowledge is established in the next section. Section 3 discusses the estimation procedure of our dynamic panel data model and results of the estimation are presented in section 4. The last section concludes.

THE MODEL

The analysis is based on the approach introduced in the 1950s that views the residual of a Cobb-Douglas aggregate production function as the technology component. The limitations of using a TFP approach are acknowledged in this article; it does not capture the systemic factors that determine the capacity to create knowledge, and therefore play a large part in driving economies apart. However, owing to the fact that it continues to inspire policy prescriptions, the paper attempts to integrate a variable that captures domestic knowledge, which is generally excluded from an analysis of developing countries despite its importance, to determine whether the significant and positive results obtained in other studies can be confirmed.²

$$Y = AF(K, H, L) \quad (1)$$

Output depends on technology A , physical capital K , human capital H and labour L . One way of increasing output consists in increasing labour and/or investing in physical and human capital. However, growth of output ultimately yields to diminishing returns. The second way requires the improvement of the efficiency with which factor inputs are used, i.e. improving technology A , and it results in sustainable growth.

In his estimates on productivity growth in the US economy, Solow (1957) found that technical change accounted for 80 per cent of per capita growth while capital accumulation accounted for the remaining 20 per cent. Easterly and Levine (2002) also found that technology, other than that incorporated in inputs, plays a fundamental role in growth. Technology or that 'something else' (as they termed it) was found to constitute two thirds of output while inputs accounted for only one third. Our study focuses on this technology term A .

Technological knowledge A is the component that permits countries to take off and maintain sustainable growth because it leads to an increase in output per unit input. Changes in the productivity of production processes

are usually measured by variations in total factor productivity, the efficiency with which factor inputs are used. Cross-country differences in total factor productivity reflect differences in technology level. Total factor productivity is thus taken as a measure for the contribution of technical change to growth (Kaldor, 1957).³

MEASUREMENT OF TOTAL FACTOR PRODUCTIVITY

A production function approach is used to relate total factor productivity to domestic and foreign innovation efforts. A Cobb-Douglas specification for aggregate production appears appropriate in the determination of total factor productivity since the rates of return to factor inputs form constant proportions of national income over time, which is one of stylised facts of economic growth (Kaldor, 1961).

Mankiw et al., (1992) integrate human capital in the textbook Solow growth model, which assumes a Cobb-Douglas production function. The resulting so-called 'Augmented Solow model' takes the time spent in school as a measure of human capital investment. However, their integration of schooling in the Cobb-Douglas specification for aggregate production has a drawback: the rate of return to schooling is inversely proportional to years of schooling in the workforce, consequently implying high returns to schooling in countries with low stocks of education. Bloom et al., (2004) note that in microeconomic studies, returns to education are found to be constant across countries, but no systematic variations of returns to schooling with income or years of schooling of the workforce are observed.

The paper uses a standard production function in which aggregate production results from physical capital and human capital adjusted labour inputs,

$$Y_{it} = AK_{it}^{\alpha} (e^{\phi s} L_{it})^{1-\alpha} \quad (2)$$

where $e^{\phi s} L_{it} = h L_{it} = H_{it}$

Y is the output, A is technology, K is physical capital, H is human capital (skilled labour) which is produced from raw labour (unskilled labour) L by means of education, and where s represents the average time spent in school (it is the ratio of total time spent in school to total labour force and is taken to be a proxy for human capital investment), while ϕ is the natural rate of return to schooling. Human capital is a simple Mincerian function of schooling.⁴ The subscripts i and t denote country and time respectively.

The parameters of the production function are represented by α and $(1 - \alpha)$. Each factor earns its marginal product so that α is the share of national income that goes to capital while $(1 - \alpha)$ is the share of national income that goes to wages of the labour force. The total wage payments

$(1 - \alpha)Y$ do not distinguish between returns to raw labour and returns to schooling. The marginal product of an extra year of schooling is ϕY while the marginal product of a worker is $\frac{(1 - \alpha)Y}{L}$.

In the analysis, it is assumed that an extra year of schooling adds proportionately to output regardless of the level of schooling of the worker obtaining an extra year of schooling.⁵ The marginal benefit of an extra year of schooling is the same for all workers regardless of the time spent in school by an individual worker.⁶

The log of output per labour unit i depends on log capital per worker (capital intensity) plus log of human capital intensity and other factors captured in the residual. Dividing both sides of the specified aggregate production function by labour, taking the logs and dropping the indices for simplicity yields,

$$\log(Y/L) = \log A + \alpha \log(K/L) + (1 - \alpha) \log(e^{\phi s} L/L) \quad (3)$$

Extracting total factor productivity and using lower case notation to indicate logs yields,

$$p_{it} = y_{it} - k_{it} - (1 - \alpha) \phi s_{it} \quad (4)$$

where $\log A$ is represented by p_{it} .

ANALYSIS OF TOTAL FACTOR PRODUCTIVITY GROWTH

The analysis relates total factor productivity to both foreign and domestic knowledge. This production function approach is one of the main methods used in analysing the impact of foreign knowledge on domestic productivity in a regression framework. Economic literature identifies four sources that contribute to the improvement of productivity; domestic sources on the one hand that include domestic R&D and outward FDI, and foreign sources on the other hand which are made up of foreign R&D (via imports and partnerships/licensing) and inward FDI.

Improvement of total factor productivity is a process that results from learning and innovation efforts of both domestic and foreign firms. As noted earlier, innovation efforts by domestic firms lead to the creation of an absorptive capacity without which foreign technology is not likely to benefit domestic economies. The term absorptive capacity is used to refer to the ability to improve productivity through the adoption and application of foreign knowledge. Thus, domestic innovative efforts boost the learning capability that is critical for take-off and subsequent catch-up, which requires foreign knowledge.

In the absence of domestic sources of knowledge, particularly domestic innovation, which normally precedes outward FDI, direct attempts to inject foreign knowledge (through, for example, high-technology content goods) are bound to penalise the learning process that leads to knowledge accumulation by provoking a fall in labour productivity. Furthermore, to a large extent foreign knowledge is induced by the presence of an absorptive capacity: the absence of an absorptive capacity, which reflects a weak learning process, inhibits foreign knowledge diffusion into domestic economies.

The implication here is that omission of domestic sources of knowledge from the estimation, as is often the case in empirical studies dealing with developing countries whose domestic innovation efforts are feeble while outward FDI is practically non-existent, may lead to bias of estimates as discussed later in more detail.

(a) Foreign R&D

It is assumed that foreign knowledge resulting from R&D efforts is transmitted to developing countries through imports of high technology content capital goods. v_{it}^M captures the real R&D intensity embodied in imports following Lichtenberg and van Pottelsberghe de la Potterie (1996). An argument is put forward regarding the effect of foreign R&D capital stock on developing countries as occurring primarily and perhaps entirely through the indirect channel of trade since licensing/partnerships occur almost exclusively amongst industrialised countries. Thus foreign R&D capital stock of a country is represented by,

$$v_i^M = \sum_j (v_j^d / y_j) m_{ij} \quad (5)$$

where i and j represent the developing country and the industrialised country indexes respectively, v_j^d represents the domestic R&D capital stock of the industrialised country, is the total imports of the developing country i from the industrialised country j , m_{ij} and y_j represents the GDP of the industrialised country j . The R&D intensity in the industrialised country is represented by v_j^d / y_j , but since the same group of industrialised is used as the trade partners for developing countries, the R&D intensity of industrialised countries is a constant term that may be eliminated from the equation.⁷

(b) Inward FDI

Foreign knowledge embodied in inward FDI is computed to capture the intensity of foreign R&D in inward FDI. Thus,

$$v_i^{FDI} = \sum_j s_{ij} (v_j^d / k_j) \quad (6)$$

where s_{ij} is the inward FDI flows of the developing country i emanating from the industrialised country j , while v_j^d represents the domestic R&D capital stock of industrialised country j , and k_j is the capital stock of the industrialised country j . The R&D intensity of capital stock of industrialised countries may be interpreted as a constant because the same group of industrialised countries is maintained. It is therefore, eliminated from the equation.

(c) Domestic knowledge

While domestic innovation via both domestic R&D and outward FDI, has been found to play a critical role in productivity growth, particularly with regard to studies on industrialised countries, most empirical studies on developing countries do not account for it. The argument put forward is that developing countries' domestic innovation is insignificant and worse still, data is unavailable. Although this argument may be somewhat valid, it is considered that the inclusion of a variable in the estimation specification reflecting the insignificance of domestic innovation is crucial.

To the extent that domestic innovation creates technological knowledge that is instrumental in the initial creation of an absorptive capacity, which has been identified as the element responsible for take-off and catch-up, it is important to identify a variable that relates to the absorptive capacity. Such a variable would enable us to gain some understanding of why some countries are unable to take-off, and in some cases recede further into marginalisation.

It is noted that building-up of the learning capability, which allows the creation of an absorptive capacity, must take place during the pre-catching-up phase if take-off is expected to occur; as suggested by Cohen and Levinthal (1990) prior knowledge, which at the most elementary level includes basic skills, is the foundation for the 'initial' absorptive capacity. It is assumed therefore, that learning capability fundamentally determines the creation and development of an initial stock of knowledge that triggers the cumulative and interactive process between knowledge stock and absorptive capacity, and thus sparks take-off.

In more general terms, the creation of a prior technological knowledge is closely tied to human capital development. Creation of knowledge arises from a variety of sources such as formal education, vocational training, in-firm training, learning on the job, and specialised employee training outside the firm (Lall, 2000). The nature of formal education and vocational training in the economy determines the level of sophistication in the

technologies employed. Modern technology requires fairly high levels and broad coverage of formal education and training. Hence, in-firm training, on the job learning, and specialised employee training outside the firm are calibrated on the base of formal education and training available in the economy.

Indeed, economic literature argues that human capital contributes to production directly (marginal product) and indirectly by inducing foreign knowledge – via capital imports of high technology contents, inward FDI, and licensing (in the case of industrialised countries) – and facilitating its use resulting in enhanced productivity growth. The indirect mechanism relies on competence creation, which occurs via domestic innovation. Domestic innovation is knowledge intensive and, hence, thrives upon human capital (Romer, 1990). The productivity enhancing effect of human capital is increasingly identified as the link between education and growth: education policies oriented towards requirements in the business sector play a determinant role in economic performance. Hence, human capital is critical in an estimation specification explaining productivity growth.

A term relating the effects of human capital on productivity with the technological distance from the frontier appears relevant to the estimation specification. Since the interest lies in the indirect rather than direct effect of human capital on productivity in the definition of this variable, it is perhaps more interesting to interact it with a term that relates to the efficiency level, which may be referred to as the distance to the technological frontier: an estimation specification with an interaction coefficient may provide more accurate results.

The distance from the technological frontier, or backwardness, may be viewed as the efficiency level of a country, which reflects the ‘quality’ of the innovation system defined to include economic, social and political infrastructures and institutions. This would probably give a more accurate specification and perhaps remedy the problem of variable omission that ultimately leads to bias of estimates. Measurement of the ‘quality’ of the innovation system or the efficiency level is a major concern.

One way in which empirical literature resolves this measurement problem consists in using the GDP ratio of machinery equipment imports to reflect the technological distance of a country from the frontier (Mayer, 2001; Coe et al., 1997). It is noted that the term obtained from interacting the GDP ratio of machinery equipment imports with human capital mirrors to some extent the absorptive capacity of country: the larger the ratio, the greater the indirect effect of human capital, which implies a greater capacity to reach the technology frontier through the cumulative and interactive process between knowledge stock and the capacity to assimilate foreign knowledge.

ESTIMATION⁸

Our estimation specification is defined as a state dependent model,

$$p_{it} = \phi p_{it-1} + \beta_1 v_{it}^M + \beta_2 v_{it}^{FDI} + \beta_3 v_{it}^D + \lambda_t + \mu_i + \omega_{it} \quad (7)$$

where the total factor productivity is denoted by p_{it} , the lagged dependent variable by p_{it-1} , foreign R&D by v_{it}^M , inward FDI by v_{it}^{FDI} , and domestic knowledge v_{it}^D . Ideally, the domestic knowledge variable should be represented by domestic R&D and outward FDI. It is assumed that developing countries do engage in these two activities in one way or another, but data is not available for the whole sample.⁹ Therefore, in the estimation domestic knowledge v_{it}^D is replaced with an interaction term between human capital and the efficiency of production (GDP ratio of machinery and equipment imports as a proxy of production efficiency).¹⁰ The country specific variable (representing for example geography) is denoted by μ_i , and λ_t denotes a time effect (captures the effect of the time variant technology frontier) such that $\lambda_{it} = \lambda_t + v_{it}$ where is included in the error term ω_{it} .

Path dependence is a major factor influencing technology acquisition: it appears reasonable to assume that past productivity influences current productivity. In addition, past productivity may influence the other explanatory variables as discussed in the next subsection in greater detail. A dynamic model appears appropriate.

The standard methods that are used to estimate panel data models are fixed effects or random effects with the major difference between the two being the information utilised to calculate the coefficients: the fixed effect estimates are calculated from differences within each country across time and the method does not account for the presence of unobserved time invariant characteristics (it simply absorbs them into the fixed effects), while the random effects estimates incorporate information across individual countries as well as across periods. Although the random effects' estimates may be more efficient, the method requires that the country specific effects be uncorrelated with the explanatory variables for estimates to be consistent which is often unlikely. A Hausman specification test may to some extent be used to evaluate whether this independence assumption is satisfied.

Hausman and Taylor (1981) propose the use of an instrumental variables' estimation as a way to overcome the problem of bias in the estimates. Their approach entails transformation of the model to deviations from country means in order to get rid of the country specific effects that are correlated with the explanatory variables. The country mean deviations are used as instrumental variables to obtain consistent estimators.

However, even though the instrumental variable estimator is consistent it may not be efficient; correlation between the explanatory variables and the disturbance may still exist. Furthermore, the presence of a lagged dependent variable in our model makes the Hausman & Taylor approach inappropriate as it is not directly applicable to a dynamic model: the presence of a lagged dependent variable in the model violates the assumption of strict exogeneity because the lagged endogenous variable is bound to be correlated with the error term. In addition, since the time series dimension is fixed ($t = 21$ or $t = 5$ i.e. t does not approach infinity), the estimation is not consistent even as n goes to infinity. Hence, the bias for the coefficient of the lagged endogenous variable may be significant.

Arellano and Bond (1991) suggest an alternative estimation technique that corrects for the bias introduced by the lagged endogenous variable, and in addition, permits a certain degree of endogeneity in other regressors. A more detailed discussion of the model is presented below.

EFFECTS OF THE ABSORPTIVE CAPACITY ON PRODUCTIVITY GROWTH

The growth of total factor productivity is examined using a sample of 51 developing countries over the period 1981–2000.¹¹ The productivity growth equation:

$$p_{it} - p_{it-1} = (\phi - 1)p_{it-1} + \beta_1 v_{it}^M + \beta_2 v_{it}^{FDI} + \beta_3 v_{it}^D + \lambda_t + \mu_i + \omega_{it} \quad (8)$$

may be rewritten as:

$$p_{it} = \phi p_{it-1} + \beta_1 v_{it}^M + \beta_2 v_{it}^{FDI} + \beta_3 v_{it}^D + \lambda_t + \mu_i + \omega_{it} \quad (9)$$

The model holds for the years 1981 to 2000 with p_{i0} corresponding to 1980, the first year of data. It is assumed that one lag of the dependent variable, p_{it-1} is sufficient to capture the dynamics in the conditional expectation and any further lags on p_{it} or lags on the other explanatory variables are unimportant (the inclusion of p_{it-1} in the model along with other explanatory variables is intended to control for another source of omitted variable bias). The value of ϕ need not be restricted given that the analysis is based on fixed time asymptotics. The coefficient of interest is on the domestic knowledge indicator v_{it}^D which captures the absorptive capacity of a country. A robust and positive β_3 is expected.

One implication of the above model is that the lagged dependent variable is correlated with the disturbance (even if it is assumed that the disturbance itself is not auto-correlated) because of a possible bias by the individual specific effects since the same specific effect enters the equation for every

observation in each group. $E(\omega_{it} | p_{it-1}) \neq 0 \quad t = 2, 3, \dots, T$ and an estimation of the model using the usual techniques would lead to an inconsistent estimator. Arellano and Bond propose an alternative estimation technique that corrects the bias introduced by the lagged dependent variable. The idea consists in first differencing the productivity growth equation,

$$p_{it} - p_{it-1} = \phi(p_{it-1} - p_{it-2}) + \beta_1(v_{it}^M - v_{it-1}^M) + \beta_2(v_{it}^{FDI} - v_{it-1}^{FDI}) + \beta_3(v_{it}^D - v_{it-1}^D) + (\lambda_t - \lambda_{t-1}) + (\omega_{it} - \omega_{it-1}) \quad (10)$$

Equivalently,

$$\Delta p_{it} = \theta_t + \phi \Delta p_{it-1} + \beta_1 v_{it}^M + \beta_2 v_{it}^{FDI} + \beta_3 v_{it}^D + \omega_{it} \quad (11)$$

where time dummies are represented by $\theta_t = \lambda_t - \lambda_{t-1}$.

The first differencing transformation eliminates the country dummies (unobserved country effects) μ_i , and thus the bias introduced by the lagged dependent variable, and therefore allows the use of a simple instrumental variable estimator.¹² However, correlation between the lagged dependent variable and the disturbance still exists since past productivity influences the current level of foreign R&D spillovers, inward FDI and domestic knowledge: $V_{it} = \xi p_{it-1} + \alpha_t + \phi \mu_i + \varepsilon_{it}$ where $V_{it} = (v_{it}^M, v_{it}^{FDI}, v_{it}^D)$. Lagged values of each of the independent variables are used as instruments so as to remedy the correlation problem between the explanatory variables and the disturbance $E(\omega_{it} | V_{it}) \neq 0 \quad t = 1, 2, 3, \dots, T$.

$$E(V_{it} \omega_{it}) \begin{cases} \neq 0 & \text{if } 0 \leq t < T \\ = 0 & \text{if } 0 \leq t > T \end{cases} \quad V_{it} \text{ is predetermined and not strictly exogenous.}^{13}$$

RESULTS

Table 1 below reports estimates of the productivity growth equation using fixed effects, random effects, Hausman & Taylor procedure and the Arellano & Bond GMM technique. Estimates vary depending on the technique that is used, making it necessary to test the validity of the assumptions underlying each method. First a Hausman specification test comparing the fixed-effects estimates in column [1] with the random effects in column [2] rejects the assumption that country specific effects are uncorrelated with the explanatory variables as is required for random effects. Nonetheless, both methods are inconsistent due to the presence of the lagged endogenous variable.

The coefficients of the Hausman & Taylor estimator reported in column [3] are virtually similar to those obtained by the fixed effects estimator in column [1] suggesting that specific effects do not bias the model and should therefore

be included in the estimation equation. However, coefficients of the lagged dependent variables obtained by the Arellano & Bond approach used in column [4] are large and highly significant, suggesting that this method is preferable to the Hausman & Taylor technique used in column [3] whose estimates are inconsistent because it is also a static model (it does not take into account the lagged dependent variable). This is an informal way of selecting between the static and dynamic model since no formal test exists. The presence of a lagged dependent variable points, *a fortiori*, to a dynamic rather than a static model. It is noteworthy that had the coefficients obtained in column [4] not been robust this would have indicated the need to perhaps redefine the estimation specification; a state dependent model would not have been appropriate.

Estimates obtained using lagged instruments of the explanatory variables or regression of explanatory variables on the lagged dependent variable, suggest that past productivity influences the current level of the explanatory variables. For example, regressing foreign R&D spillovers on the lagged dependent variable suggests that past productivity influences the current level of foreign R&D spillovers, i.e. $v_{it}^M = \xi p_{it-1} + \alpha_t + \phi \mu_i + \varepsilon_{it}$. This implies that $V_{it} = (v_{it}^M, v_{it}^{FDI}, v_{it}^D)$ are predetermined by at least one period. Although endogeneity may exist between knowledge variables and $V_{it} = (v_{it}^M, v_{it}^{FDI}, v_{it}^D)$ productivity growth, the test for autocorrelation and the Sargan test of over-identifying restrictions satisfy the underlying assumptions of the Arellano & Bond approach suggesting that estimates reported in column [4] are consistent and efficient.¹⁴

The coefficients of both the lagged dependent variable (lpdvty), and the foreign R&D variable (fkm) are positive and highly significant in all estimation techniques as expected. In addition, coefficients of the lagged dependent variable are fairly large, suggesting that past productivity plays a crucial role in future productivity.

The variable representing foreign knowledge via FDI (fkfdi) gives mixed results in columns [4] to [7]. The original Arellano & Bond dynamic panel data estimator in column [4] reports a positive but insignificant coefficient. This result is improved by the Arellano & Bond ‘difference GMM estimator’ in column [5], which is better than the original model. It provides a finite sample correction to the two-step covariance matrix that compensates for the severely down biased two-step estimates of the standard error, obtained in the original model. However, lagged levels in both the original Arellano & Bond estimator as well as the ‘difference GMM estimator’ are usually poor instruments for the first differences, and especially for variables which are close to a random walk, which is the case in the explanatory variables of the model, and are therefore probably biased.

Indeed, the Arellano & Bond ‘system GMM estimator’ in column [6], which is an augmented version of the ‘difference GMM estimator’, does not confirm the result in column [5]. In the augmented version, original

equations in levels are added so as to provide additional moment conditions that are used to increase the efficiency of the estimates. The 'system GMM estimator' reports a negative coefficient, but it is not significant. In a further step, 'more developed' developing countries are removed from the regression and an estimation is carried out for five 5-year periods, which implies that $t = 5$ instead of $t = 21$.¹⁵ This mitigates the problem of loss of degrees of freedom. A negative and highly significant coefficient for foreign knowledge via FDI is obtained from the 'system GMM estimator'. A similar regression is carried out for the 'more developed' developing countries. A positive and significant coefficient is obtained for this group of countries. These results appear particularly interesting and lead to the conclusion that potential benefits of FDI accrue only to the small group of 'more developed' developing countries that engage in domestic investment and thus, dispose of a relative absorptive capacity. Indeed, these are also the countries that would be able to attract market seeking FDI (horizontal FDI that is more pervasive in introducing foreign knowledge than vertical FDI), rather than serve as mere export platforms (vertical FDI).

This finally brings us to the coefficient of main interest, domestic knowledge (dk), which gives the expected result: the coefficient is negative and highly significant in all estimation techniques except for the original Arellano & Bond estimator in column [4], which reports a non significant coefficient, while the Arellano & Bond "difference GMM estimator" reports a significance level of 5 per cent. One interesting observation is that the coefficient remains negative throughout. It supports the initial view that although the commonly used interaction coefficient between human capital and the GDP ratio of high technology imports may to some extent depict the absorptive capacity of a country it mainly portrays openness of an economy. This may lead to the conclusion that opening up fragile economies is likely to result in a negative effect on the productivity growth of these economies. Although economic research on the role of openness in developing countries has led to mixed results, a number of interesting papers including Fagerberg and Verspagen (2004) find that opening up weak economies is detrimental to growth.

CONCLUSIONS

The results support the view that foreign knowledge generates a beneficial impact on the economic performance of the few developing countries that have been successful in embarking on an innovation-driven growth path by simultaneously engaging in technical competence creation and innovation. This is particularly evident for foreign knowledge via FDI. With regard to foreign R&D, the results suggest positive and highly significant benefits

for the whole sample. However, it may be argued that the calculation of the foreign R&D variable is based on imports of high technology content capital and machinery, which mainly capture openness and do not necessarily suggest significant spillovers. More specifically, efforts to inject foreign knowledge through high technology content imports in weak economies are bound to penalise the learning process that leads to knowledge accumulation by provoking a fall in labour productivity. Devarajan et al.'s (2001) study on Sub-Saharan Africa revealed that an increase in capital accumulation in Tanzania led to a fall in output per unit of labour and consequently a fall in output per unit of capital due to under-utilisation.

Estimation of the dynamic panel data model using alternative methods, for example the Kalman filter, to infer data for domestic knowledge may have provided an interesting basis for comparison with estimations that use the interaction coefficient between human capital and the GDP ratio of high technology imports as a proxy for domestic knowledge. However, it is noted that the explanatory power of linear models may be quite limited as concerns the absorptive capacity. The absorptive capacity is most probably represented by a sigmoid function, a functional form that approximates the stylised S-shaped function of technology diffusion models. A nonlinear logistic specification is much more likely to be robust. Benhabib and Spiegel's (2002) estimation of a logistic specification reveals that divergence is a possible outcome for countries with no absorptive capacity.

To the extent that a solid technological infrastructure is indispensable for sustained growth, and that investment in knowledge producing activities may be scarce as is the case in most developing countries, there is a rationale for public intervention with strong policy co-ordination that favours technological shifts. Admittedly, limited innovation may be caused by such factors as inadequate environment for risk taking, unavailability of information about technological opportunities, inadequate inputs (particularly competences), and taxation systems that fail to induce industrial activities.

APPENDIX 1: COUNTRY SAMPLE

Country list of 51 developing countries used in the analysis
(definition of developing countries is that of the WTO)

Africa (21 countries)	Latin America (17 countries)	Asia (13 countries)
Algeria	Argentina	Bangladesh
Benin	Bolivia	China
Cameroon	Brayil	Honk Kong

Africa (21 countries)	Latin America (17 countries)	Asia (13 countries)
Central African Republic	Chile	India
Congo, Dem. Rep.	Colombia	Indonesia
Congo, Republic of	Costa Rica	Korea, Republic of
Egypt	Ecuador	Malaysia
Ghana	El Salvador	Nepal
Kenya	Guatemala	Pakistan
Malawi	Honduras	Philippines
Mali	Mexico	Singapore
Mauritius	Nicaragua	Sri Lanka
Mozambique	Panama	Thailand
Niger	Paraguay	
Rwanda	Peru	
Senegal	Uruguay	
Togo	Venezuela	
Tunisia		
Uganda		
Zambia		
Zimbabwe		
'more developed' developing countries (group one countries)	Other developing countries (group two countries)	
Argentina	Algeria	Mauritius
Brazil	Bangladesh	Mozambique
Chile	Benin	Nepal
China	Bolivia	Nicaragua
Egypt	Cameroon	Niger
Hong Kong	Central African Republic	Panama
India	Colombia	Paraguay
Indonesia	Congo, Dem. Rep.	Peru
Korea, Republic of	Congo, Republic of	Philippines
Mexico	Costa Rica	Rwanda
Pakistan	Ecuador	Senegal
Singapore	El Salvador	Sri Lanka

Africa (21 countries)	Latin America (17 countries)	Asia (13 countries)
Thailand	Ghana	Togo
Venezuela	Guatemala	Tunisia
	Honduras	Uganda
	Kenya	Uruguay
	Malawi	Zambia
	Malaysia	Zimbabwe

A sample of 22 advanced countries used in the analysis: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Italy, Ireland, Luxembourg, Netherlands, Portugal, Spain, Sweden, United Kingdom, Australia, Canada, Japan, New Zealand, Norway, Switzerland, United States of America.

DATA

Capital stock

The initial physical capital stocks are calculated using the method proposed by Klenow and Rodriguez-Clare (1997)¹⁶

$$\frac{K}{Y}_{1980} = \frac{I_K/Y}{g + d + n} \quad (1)$$

where I_K/Y is the average investment rate in physical capital (1980–2000), is an estimation of the world average growth rate of output per capita Y/L given as 0.02, d represents the rate of depreciation which is set at 0.03, and n is the rate of growth of the working population 15–64 year olds (1980–2000). The depreciation rate is taken from Mankiw et al., (1992) based on a calculation for a large sample of countries. Although the depreciation rate for fast growing developing countries may vary widely, data that would allow the estimation for country-specific depreciation rates for the whole sample is not available. The physical capital stock of a country in period satisfies as in Benhabib and Spiegel (1994) the equation:

$$K_{it} = \sum_{\varepsilon=0}^t (1-d)^{t-\varepsilon} I_{i\varepsilon} + (1-d)^t K_{1980} \quad (2)$$

Data for real income (PPP GDP), employment/labour (population) and PPP investment in physical capital are from the Penn World Tables version 6.1 (2002). Data for schooling, which is given as the average years of schooling in the population above 25 years of age, is obtained from Barro and Lee's

data set (2000). The constant marginal rate of return to physical capital is set at $\alpha = 1/3$. The assumption of $\alpha = 1/3$ is based on Bernanke and Gurkaynak's (2001) calculation of the labour share of 0.65 and by implication a capital share of 0.35¹⁷. The rate of return to schooling $\phi = 0.085$.

FOREIGN R&D

Data on machinery and transport equipment is obtained from the UN Comtrade database section 7 of SITC Rev. 2 from which consumption goods as well as parts and components imported by developing countries for re-export after incorporating some form of value added are omitted. The analysis is based on mirror trade data: imports by developing countries are assumed to be equivalent to exports by partner (industrialised) countries, due to the unavailability and unreliability of import data of most developing countries. The breakdown is as follows:

Machinery: SITC Rev. 2: 71-77 less 761-3, less 775-776

Transport & Equipment: SITC Rev. 2: 78-79

INWARD FDI

Data is from UNCTAD Foreign Direct Investment Database (2004). The database presents aggregate inward FDI stocks. It is assumed that the inward FDI stocks in developing countries emanating from the world rather than from the selected group of industrialised countries does not significantly alter results. In addition, it is noted that inward FDI may not constitute a significant channel through which knowledge is diffused: inward FDI may not contribute to the improvement of the host country's productivity since the foreign owner has no incentive to share technology and may prefer to adapt to the host country's technology. Indeed, inward FDI typically takes place via a wholly owned subsidiary in a bid to keep technology under the control of the multinational.¹⁸

DOMESTIC KNOWLEDGE

The domestic knowledge variable of a country is defined as an interaction term between human capital and the GDP ratio of machinery equipment imports. The GDP ratio of machinery equipment imports is calculated using the UN Comtrade database section 7 of SITC Rev. 2 as described above and GDP from Penn World Tables. The human capital data is obtained from Barro and Lee (2000) who generate a comparable estimate for a large sample of countries. The underlying condition in this approach, however, is that there

exists an adequate level of human capital, which brings us back to the importance of building what was referred to as a learning capability. In other words, direct attempts to inject foreign knowledge in economies that are poorly endowed in human capital may penalise the learning process that leads to knowledge accumulation by provoking a fall in labour productivity.

APPENDIX 2: DETERMINATION OF INSTRUMENTS

The instruments are determined as follows:

For the period $t = 3$ the productivity equation may be written as:

$$p_{i3} - p_{i2} = \phi(p_{i2} - p_{i1}) + \beta(V_{i3} - V_{i2}) + \theta_t + (\omega_{i3} - \omega_{i2}) \quad (1)$$

In the third period may serve as an instrument since it is highly correlated with $(p_{i2} - p_{i1})$, but uncorrelated with $(\omega_{i3} - \omega_{i2})$ if ω_{it} is a white noise. As for $(V_{i3} - V_{i2})$, V_{i1} and V_{i2} are valid instruments since they are not correlated with the error term $(\omega_{i3} - \omega_{i2})$. [Level instruments are preferable to difference instruments. Orthogonality conditions are stated in terms of the levels of the variables and the differences of the disturbances $E(V_{i3}\Delta\omega_{it}) = 0$ as opposed to differences of both the variables and the disturbances which is implied $s = 1, \dots, t-2$, Arellano (1989).

The matrix of instruments may be written as:

$$Z_i = \begin{bmatrix} p_{i1}, V_{i1}, V_{i2}d_{1982} & \dots & 0 & 0 \\ p_{i1}, p_{i2}, V_{i1}, V_{i2}, V_{i3}d_{1983} & \ddots & & \\ \vdots & \ddots & & \\ 00 & \dots & p_{i1}, \dots, p_{iT-2}, V_{i1}, \dots, p_{iT-2}d_{2000} \end{bmatrix}$$

d_{year} represents the year specific dummy variable.

Once the instruments are identified the instrumental variables method is applied to the first differenced productivity equation

$$\Delta p_{it} = \theta_t + \phi \Delta p_{it-1} + \beta \Delta V_{it} + \Delta \omega_{it} \quad (2)$$

Let $|\phi| = \delta$. A convergent estimator of the parameter is obtained but, the GMM estimator of δ may not be efficient since (ω_{it}) is a random walk with a unit root: $\omega_{it} - \omega_{it-1} = \Delta \omega_{it}$ hence, $\omega_{it} = \omega_{it-1} + \Delta \omega_{it}$ is a random walk since it is assumed that $\Delta \omega_{it}$ has no serial correlation (it is a white noise).

It was assumed that the first difference of the idiosyncratic errors $\Delta \omega_{it}$: $t = 2, 3, \dots, T$ are serially uncorrelated and have constant variance.

$$E(w_i w_i' | p_{i0}, \dots, p_{iT-1}, V_{i1}, \dots, V_{iT-1} \mu_i) = \sigma_w^2 I_{T-1}$$

where w_t is the $(T-1) \times 1$ vector containing $\Delta\omega_{it} : t = 2, 3, \dots, T$.

Since this assumption may not be verified $E(w_t w_t') \neq \sigma_w^2 I_{T-1}$ a matrix of instruments $z = [z_1', \dots, z_N']$ is used such that the orthogonality conditions are now. This is the weakest assumption that can be imposed in a regression framework to get a consistent estimator of δ . Under this assumption the vector δ satisfies

$$E[Z'\Delta p - Z(p_{-1}\Delta V)\delta] = E[Z'\Delta\omega] = 0$$

or equivalently

$$E[Z'(\Delta p_{-1}\Delta V)\delta] = E[Z'\Delta p]$$

where $Z'\Delta p$ is $K \times 1$ a random vector and $Z'(\Delta p_{-1}\Delta V)$ is a $K \times K$. To be able to estimate δ , it is assumed that it is the only $K \times 1$ vector that satisfies the orthogonality condition. This implies that although this orthogonality condition is the basis for estimating δ , the rank condition is required as a sufficient assumption for identification.

The assumption of a full rank implies that the system has a unique solution – there is no over identification.

$$rank = \left(\sum_{t=0}^T E(\Delta X_{it}' \Delta X_{it}) \right) = K$$

$$\Delta X_{it} = (\Delta p_{it-1}, \Delta V_{it})$$

Time constant explanatory variables and perfect collinearity among the time varying variables is ruled out. The matrix is non-singular, which rules out the presence of linear dependence.

ESTIMATING δ

With the orthogonality conditions and the full rank assumption solving, for δ will yield a unique solution. A weighting matrix $\hat{W}$, a positive semi definite matrix, in the quadratic form to obtain $\hat{\delta}$ is used.

$$\hat{\delta} = \min_{\delta} \left[\sum_{i=0}^N Z_i'(\Delta p_i \Delta x_i \delta) \right] \hat{W} \left[\sum_{i=0}^N Z_i'(\Delta p_i \Delta x_i \delta) \right]$$

$$\text{Hence, } \hat{\delta} = \frac{\Delta p Z' W Z' \Delta p}{(\Delta p_{-1} \Delta V) Z' \hat{W} Z' (\Delta p_{-1} \Delta V)} = [(\Delta p_{-1} \Delta V) Z' \hat{W} Z' (\Delta p_{-1} \Delta V)]^{-1} [\Delta p Z' W Z' \Delta p]$$

FIRST STEP

The first choice of the weighting matrix $\hat{W}$ is,

$\hat{W} = \left(N^{-1} \sum_{i=0}^N Z_i' Z_i \right)^{-1}$ which is a consistent estimator of $[E(Z_i' Z_i)]^{-1}$

The IV estimator of δ may be written as:

$$\hat{\delta}_{IV} = ([\Delta p_{-1} \Delta V]' Z (Z_i' Z_i)^{-1} Z' \hat{W} Z' [\Delta p_{-1} \Delta V])^{-1} ([\Delta p_{-1} \Delta V]' Z (Z_i' Z_i)^{-1} Z' \Delta p) \quad (3)$$

The weighting matrix $\hat{W} = \left(\frac{1}{N} \sum_{i=0}^N Z_i' Z_i \right)^{-1}$ gives the initial consistent estimator $\hat{\delta}$, but may not be necessarily the asymptotically efficient estimator. However, it is important because a preliminary consistent estimator of δ is required to obtain the asymptotically efficient estimator.

SECOND STEP

The optimal weighting matrix that produces the GMM estimator with the smallest asymptotic variance is,

$$\hat{W} = \left(\frac{1}{N} \sum_{i=0}^N Z_i' \Delta \hat{\omega} \Delta \hat{\omega}' Z_i \right)^{-1}$$

The optimal GMM estimator of δ may be written as:

$$\hat{\delta}_{GMM} = ([\Delta p_{-1} \Delta V]' Z \hat{W} Z' [\Delta p_{-1} \Delta V])^{-1} ([\Delta p_{-1} \Delta V]' Z \hat{W} Z' \Delta p) \quad (4)$$

Columns [8] and [9] distinguish between 'more developed' (group one) and 'less developed' (group two) developing countries

NOTES

- 1 Nelson and Winter (1982) articulated the evolutionary theory of firms and markets, Rosenberg (1983) the chain linked model as an alternative to the linear model and Freeman (1987) empirical findings.
- 2 See for example Coe and Helpman (1997), Mohnen (2001).
- 3 In growth accounting, an index that combines all measurable inputs is estimated and used to measure the rate of growth of national income, i.e. to measure total factor productivity. However, a fundamental difficulty in modelling total factor productivity is that no independent measure for it exists.
- 4 Klenow and Rodriguez-Clare (2004) note that although a more complete Mincerian formulation would include years of experience in addition to schooling, taking experience into account has little effect on aggregate levels and growth rates. We therefore adopt the schooling only view of human capital production.
- 5 The effect of schooling on the wages of an individual has been analysed based on the work of Mincer (1974) where a semi-log equation is used to demonstrate that returns to schooling are constant across countries: $\log W_j = \alpha_0 + \alpha_1 S_j$ where W_j is the wage

of an individual j and S_j his years of schooling. An extra year of schooling increases wages by the amount $\alpha_1 W_j$. The rate of return to schooling α_1 is taken to be the same for each worker regardless of the time spent in school by the individual. The wage equation suggests that returns to uneducated workers α_0 do not depend on the level of schooling in the workforce (Bloom *et al.*, 2004). This problem does not appear in the aggregate production function proposed as it is specified in such a way that the wage of an uneducated worker depends on the average level of education.

- 6 However, the formulation of aggregate production that we adopt may imply that the rate of return to schooling is equivalent to the social rate of return of a worker. Bloom *et al.* (2004) propose the formulation $Y_{it} = AK_{it}^\alpha e^{\phi S} L_{it}^{1-\alpha}$ where $e^{\phi S} L_{it} = H_{it}$ which implies that the social rate of return for an average worker is $= \frac{\phi}{(1-\alpha)}$. It can be demonstrated, nonetheless, that different workers face different social rates of return to schooling, $\frac{\phi}{(1-\alpha) + \phi(s_j - s)}$ where s is the number of years of schooling of a worker j , while s is the average years of schooling in the labour force. This is a limitation that occurs in any aggregate production that depends only on average (total) years of schooling as it makes the assumption that the marginal benefit is the same for all workers regardless of level of schooling, while the cost of schooling takes into consideration the education level of each worker in determining the output forgone by withdrawing a worker from the labour force. An aggregate production function that maintains the Mincer equation property, that the rate of return to education is the same for all workers should include distribution as well as the average level of human capital. In the interest of simplicity, we follow Bloom *et al.* (2004) and assume that only the total stock of education matters and not its distribution.
- 7 The group of industrialised countries is indicated in Appendix 1.
- 8 See Appendix 1 for data sources, data analysis and computation of capital stock.
- 9 R&D and outward FDI data is available at least for some of the group one countries, further analysis is not undertaken because the aim is to compare group one with group two.
- 10 An alternative way of estimating domestic knowledge ν_{it}^D could be based on the Kalman filter to infer the 'quality' of the systems of innovation.
- 11 See Appendix 1 for country sample.
- 12 See Appendix 2 for further details.
- 13 We note that does not require that future exogenous variables be uncorrelated with disturbances: so that a feedback mechanism is allowed from to. However, the explanatory variable must be predetermined by at least one period:)
- 14 Although the Sargan test is satisfied, we note that one of its requirements is that the error terms must be homoscedastic whereas in our case they are heteroscedastic implying that the extent to which the test can confirm the validity of instruments is limited.
- 15 See Table 2 in Appendix 2 for results of the two groups of developing countries.
- 16 A similar method is used by Bernanke and Gurkaynak (2001) where $K_{1980} = I_{1981} / (g + d)$ where g is the growth rate of output and d the rate of depreciation.
- 17 This computation assumes that perfect competition in factor markets and more closely reflects industrialised countries. It nevertheless, gives a reasonable indication of minimum acceptable rate of return to capital; the aim of the analysis is not to demonstrate the limitation of this assumption of the linear model. Rather the aim is to

determine the implications of excluding a variable that represents domestic innovation (the variable is generally left out of estimation specifications for developing countries).

- 18 In their empirical study, Lichtenberg and van Pottelsberghe de la Potterie (1996) found that inward FDI flows do not constitute a significant channel of technology transfer. While their study concerns industrialised countries there is reason to believe that the results would not hold for developing countries.

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Where are the Flags of Our Fathers?

Rethinking Linkages between Social Policies and Innovation Policies

Rebecca Hanlin and Judith Sutz

SUMMARY

This paper builds on the idea that embedding social policies within innovation policies and vice versa is one of the main ways to put the might of academic research at the service of those at the bottom of the pyramid. The aim of the paper is to analyse systematically the problems that prevent research to fulfil the promise of modernity and progress for vast majorities of the world population and to propose ways to overcome such problems.

INTRODUCTION

We are all told that we live within a 'globalised knowledge economy'. This is put forward as being a positive situation leading to economic growth, progress and ultimately reduction of poverty, disease and 'backwardness'. Yet for many we are looking at a situation that could be labelled as the unfulfilled promise of knowledge-led progress. Truth is distorted while promises are made for the future that rarely becomes tangible reality. In particular we would argue that there has been a simultaneous failure for the developing world of the three flags of the French Revolution (equality, freedom, fraternity). There is more and more inequality in the world; 'development as freedom' implies 'underdevelopment as un-freedom', and so un-freedom is how we can describe the state in which most of the world population is embedded; while fraternity, or solidarity, seems to have been pushed into the realm of private life, diminishing its drive as an inspiration for public policy.

'Trickle down' strategies from economic growth, able to finance the burden of social policies, have rarely been successful in terms of advances towards sustainable processes of development. Efforts devoted to the

production and use of knowledge in developing countries have as a main justification the positive relationship between knowledge and economic growth. So, not achieving economic growth or not being able to diminish inequality through economic growth weakens the social legitimacy of such efforts; usually small and threatened by other priorities.

In this paper we provide a systemic explanation of the unfulfilled promise of knowledge for development. In so doing we further explore a possible 'interstitial' way to put knowledge at the service of those excluded from its main benefits: *to embed innovation policies in social policies and the other way around* (Arocena and Sutz, 2006). Our point of departure is modern research activities, already acknowledged as a major contributor to the knowledge economy. The aim is to extend our understanding of what these activities have to offer and how they can be conveyed to advance towards the fulfilment of the promises of knowledge and modernity in developing countries. The term 'interstitial' qualifies the strategy pursued: it aims neither to compete nor to substitute the main role of R&D and innovation in the knowledge economy, but to foster the emergence of differently oriented research and innovation agendas in interstices of the 'canonical' ways of doing research and designing public policies in actual institutions.

In Section 1 of the paper we briefly discuss some evidence that shows the failure of the 'trickle down hypothesis' to put knowledge to work to solve the needs of the poor or the excluded; the necessity for alternative approaches is thus outlined. We posit that a main new goal for innovation policies should be to foster research and innovation directly oriented towards the fulfilment of the social policy agenda; we posit as well that social policy can provide the effective demand for research and innovation that are sorely needed to foster and accumulate knowledge capacities in developing countries. In Section 2 we develop an exploration of the feasibility of this approach by presenting a preliminary taxonomy of the mismatches that hamper the use of knowledge to solve social problems and select some success stories of resolved mismatches. In Section 3 we discuss the reasons behind these successes and propose a checklist for detecting them and orienting policy design.

A CIRCUIT THAT IS NOT WORKING WELL

'Research and innovation for competitiveness + economic growth stemming from improved competitiveness + spare money to finance social policies able to redress inequalities of the past as well as the new ones' is a circuit that is not working well. We shall take as evidence the Chilean situation, because Chile is a good example of successful export-led economic growth

with a healthy and sustained investment rate and well funded and carefully designed, implemented and monitored social policies: 'In the last 20 years Chile has shown a solid economic growth expressed in a duplication in per capita income and an impressive reduction in the levels of absolute poverty. Nevertheless, inequality in income and in quality of life continues to be intolerable, leading to a growing perception of social exclusion' (Infante and Sunkel, 2009: 135).

Insisting on looking only to absolute poverty should not dismiss the importance of this perception. Two reasons can be given in support of this assertion. First, poverty is not the only problem; inequality is a problem, too. As Amartya Sen wrote: 'To be excluded from common facilities or benefits that others have can certainly be a significant handicap that impoverishes the lives that individuals can enjoy. No concept of poverty can be satisfactory if it does not take adequate note of the disadvantages that arise from being excluded from shared opportunities enjoyed by others' (Sen, 2000: 50).

A second reason has to do with the growing frustration experienced by people on the 'bad side' of extremely unequal societies, who nevertheless have growing access to information about how people live on the 'good side'. Some Latin American scholars attribute to this inequality-fed-frustration the kind of uneasiness and conflict that are threatening democratic rule in several countries and regions (Calderon, 2008: 127). This is akin to the telling metaphor of Albert Hirschman (1981: 58): tolerance to inequality is like credit that has an expiration date.

To address this problematic situation, the economic mainstream suggests insisting on reaching more economic growth and more fine-tuned social policies. Others suggest that this strategy will not help to redress the hard core of relative poverty and severe inequality, because, to achieve this, what is needed is to overcome the structural heterogeneity that usually characterises the productive structure in developing countries. Such structural heterogeneity is responsible for the marked differentiation in productivity between sectors that ends up with high levels of wage differentiation, a main source of inequality; it is also responsible for the huge informal labour market that hardly disguises situations of very low quality of life. This view is not new; it was put forward several decades ago by what was called the school of 'Latin American structuralism', developed at the Economic Commission for Latin America and the Caribbean (ECLAC). This is not the place to analyse the contribution of this view to development theory and practice in the past, and even less to assess its capacity to orient future actions towards an inclusive development. If we include it, it is because of the powerful acknowledgement it makes of the lack of success, moreover the inevitable failure, of the present blending of macroeconomic policies and social policies to redress inequality and minimise poverty.

To avoid this failure nothing less than ‘a radical change in the approach to public policies’ is needed (Infante and Sunkel, 2009: 137). We agree with this opinion. We posit that this radical change has partially to do with the way we look to the contribution of research and innovation to the problem of inclusive development. The ‘canonical’ way, that relates knowledge and innovation to the modernisation of the economic activities that act as engines of growth, put the burden of inclusion outside knowledge and innovation: it corresponds to the field of social policies. The ‘heterodox’ way suggested by the ECLAC’s approach values research, technology and innovation for its contribution to the modernisation of backward productive sectors which are seen as key in the strategy to reach inclusion through better wages and quality jobs. It thus embeds knowledge and innovation within the social inclusion strategy, but indirectly.

Both approaches relate fundamentally to the most modern capital goods, which in developing countries will surely be imported, at least the majority of them. Yet we have here a problem: these approaches leave untouched the lack of stimulus to the building, strengthening and deployment of endogenous capabilities to relate creatively with knowledge and to innovate. This is indeed a structural problem in developing countries. As Rodrik (2007: 101) put it: ‘innovation in the developing world is constrained not on the supply side but in the demand side. That is, it is not the lack of trained scientists and engineers, absence of R&D labs, or inadequate protection of intellectual propriety that restricts the innovations that are needed to restructure low-income economies. Innovation is undercut instead by lack of demand from its potential users in the real economy – the entrepreneurs.’ If social demand for endogenous knowledge production and for innovation is not fostered, they will continue to be constrained, and their usefulness for social aims will not be fulfilled.

There is another problem with these kinds of indirect approaches to the linkages between knowledge, innovation, and social inclusion. They will eventually succeed in the medium or long-term, but in the meantime, how will the exclusion from the benefits conveyed by modern knowledge and innovation be addressed?

Two main arguments appear then to back ‘a radical change in the approach to public policies’ concerning science, technology, innovation and social inclusion. The first one relates to immediateness: if innovation policies include in their mandate the needs and demands stemming from social concerns, part of the production of knowledge and its creative use will be put directly at the service of social inclusion. The second argument relates to the following virtuous circle: demand for knowledge-based strategies to deal with social problems – mobilisation of endogenous advanced problem-solving capabilities to deal with such problems – enhanced capacities to

solve them – legitimisation of endogenous knowledge and innovation – enhanced new demand, both from social policy realms and from production. The beginning of the thread is demand for endogenous capabilities: public social policy can play this role.

We hope to have conveyed convincingly the idea that new, even if interstitial policies are needed to effectively harness knowledge and innovation to grow rates of social inclusion. In the following section we further explore this approach.

OVERCOMING MISMATCHES BETWEEN INNOVATION POLICIES AND SOCIAL POLICIES

This section is devoted to discuss the feasibility of conceiving some part of innovation policies as social policies. We have already made a general argument in favour of this; we will now justify in more detail the reasons to follow this strategy.

Public officers in developing countries often face a tantalising situation. They are aware of the existence of innovations that could redress some of the most severe social burden suffered by the poorest part of the population, being at the same time aware that such solutions are out of reach or are not workable. Some solutions are too expensive, others are rejected for cultural reasons, and others are very difficult to diffuse, while for some no available infrastructure exists. Each of these situations can be seen as a mismatch between a would-be-innovation and a real innovation that effectively solves a problem; they can be further broken down and differentiated to provide a better understanding of the difficulties and actors involved. A simple taxonomy of such mismatches is presented in Table 1. Even if they are separated analytically, more often than not each type of mismatch can present some difficulties related to others.

Table 1 Taxonomy of mismatches between would-be-innovations and problem-solving innovations

Cost mismatches		Technical mismatches		Delivery mismatches		
For public policy	For private users	Delivery infrastructure	Research environment	Cultural	Political	Organisational

Major factors inhibiting successful innovations reaching the poor, often cluster around the matter of ‘cost’. Cost can affect the public sector as developer, purchaser and/or supplier of an innovative product or process. Alternatively cost can affect private users either as end consumers or as

intermediary agents who need the innovation as an input to provide a service or a product. A well-known case of a cost mismatch is that of vaccines; many other examples, also related to health, have to do with medical devices. Unaffordable vaccines and expensive medical devices that are key to save lives are typical cost mismatches for public policy. There are also cost mismatches affecting private users. In many parts of the world the private sector dominates care provision for the poorest families which means that rational medicines use is difficult when families cannot often afford to purchase all the treatment they require.

In other cases it is not always a matter of cost but one of technical requisites, although sometimes they are combined. Immunisation programmes that fail by lack of a strong cold chain fall into the taxonomy of a delivery infrastructure mismatch. At times this is not so much about technical requisites as scientific requisites. The example of AIDS vaccine research fits this part of the taxonomy due to the difficulty of matching demand requirements for a vaccine with scientific know-how. The research environment as a mismatch deserves further clarification. Sometimes the required knowledge to pursue a solution exists but it is not put to work because the problem has not been integrated into the innovation agenda of any concrete actor. Sometimes new knowledge is needed to tackle a given problem and research capabilities exist to address the task, but concrete research agendas do not include the search.

Delivery mismatches relate to failures in delivery at the most downstream of levels. Thus in many respects we are actually referring to the social issues affecting successful delivery. These include lack of political will and well designed social technologies, i.e. poor understanding of what people want or can use, and incomplete or disrupted organisational processes and institutions that are unable to make effective decisions. The difficulties of designing good performing social technologies have already been put forward: ‘...society’s ability to develop effective ‘social technologies’ is more limited and more prone to frustration than its ability to advance physical technologies’ (Nelson, 2003: 4).

Bednets as an example of an organisational delivery mismatch will be discussed below. However another example of a delivery mismatch is that of the polio vaccine and distribution efforts in countries such as Nigeria which have not been as effective as they might be in Africa due to cultural misunderstandings. A political delivery mismatch could be found in the inability to scale up the Tanzania Essential Health Interventions Project (TEHIP) project in Tanzania; a successful case of delivering quality health-care as needed by the local population based on good data collection, management and priority setting in small communities but which has not been successfully scaled up due to a lack of political will.

These mismatches can be seen as special examples, mainly occurring in developing countries, of what Lundvall termed 'unsatisfactory innovations' (Lundvall, 1985). His taxonomy of unsatisfactory innovations included 'hyper technology', that occur when unnecessary sophistication is built into a solution; 'unexploited technical opportunities', that occur when solutions are less efficient at integrating available new knowledge, and 'lack of interdisciplinary innovations', that occur when due to 'mono-cognitive' approaches, the solutions found lack the efficiency that would have been possible with a more interdisciplinary approach. Present at the source of unsatisfactory solutions were, to some extent, episodes of misunderstanding between the producers and the users of the innovations:

In all (...) cases, there was a tendency towards producer domination. In at least two of the cases the lack of competence on the user side was reinforcing the unsatisfactory trajectory of innovations. This pattern might inspire a technology policy which is more oriented towards strengthening the competence of users than to the technology policy predominating today. An extension of such a new orientation that encompass the 'final users', workers and consumers, might have radical implications (Lundvall, 1985: 23).

How can unsatisfactory innovations become satisfactory ones? Lundvall's examples point to a sort of 're-innovation process' where the perspective of users is better taken into account. Sometimes the users become proficient enough to lead this re-innovation process themselves and find solutions that can differ quite radically from those provided by the producer. Sometimes the users can better interact with the producers and convey more precisely what they need and what they want. 'Users' are not only final users, individuals or firms, but also intermediary bodies acting on behalf of other social actors. Technological public procurement is a process in which the public sphere acts as a user in the sense of defining the framework for the searched innovations; the innovation can be used by the public sphere itself or delivered by the public sphere to other actors. 'Public procurement of innovative goods and services relies on inducing innovation by specifying levels of performance or functionality that are not achievable with 'off-the shelf' solutions and hence require an innovation to meet the demand.' (Georghiou, 2007: 20) It can be said that Georghiou is referring to 're-innovation' more than to 'innovation' *tout court*; innovation of the re-innovation type is needed because 'off-the-shelf' solutions are unsatisfactory in some sense. The idea of 're-innovation of innovations' as a way of transforming unsatisfactory innovations into more satisfactory ones or as a way to overcome the mismatches between would-be-innovations and problem-solving innovations is particularly well-suited for developing countries.

To re-innovate by removing the factors that make off-the-shelf solutions unsatisfactory may need a non-canonical heuristic. Given that cost is one of the most important 'unsatisfactory' factors, be it the price of the innovation or the costs associated with the effective use of the innovation, a techno-cultural trait particularly strong in developing countries, the 'capacity to innovate in scarcity conditions' (Srinivas and Sutz, 2008), may prove to be particularly useful.

In fact, some of the successes in overcoming cost and technical mismatches are related to this type of innovation capacity. The following are concrete Uruguayan examples of perceived mismatches that have led to attempts to 're-innovate'. Some of these have already been achieved and are functioning while others are in the making with support from research councils:

- *Lamp of blue light to treat severe jaundice in new-born children*
 - Social problem involved: prevalence in 60 per cent of premature newborn children, who are more often present in the deprived population.
 - Unsatisfactory solution: lamp of blue light, either halogen with high rate of bulb failures and unaffordable replacement cost, or a very expensive LED (light emitting diode) based lamp.
 - Strategy for overcoming the mismatch: 're-innovating' by means of an optical concentrator that generates the same performance with ten times less light emitting diodes, with a radical cut in costs. Originated in a university research unit transferred to a private firm; in use in public hospitals after being approved by the public health authorities.
- *Artificial skin to treat severe burns*
 - Social problem involved: children living in slums are severely burned each winter due to fire originated in precarious heating systems.
 - Unsatisfactory solution: imported artificial skin, the cost of which makes it impossible to treat a burned arm properly, needing an investment of thousand of dollars.
 - Strategy for overcoming the mismatch: development of a cheap artificial skin through advanced materials techniques and using bovine tendon, rich in collagen, profiting from the fact that Uruguay has been certified as free of 'mad-cow' disease. Currently in an advanced research stage, supported by the 'research for social inclusion' programme of the University research council.
- *'Neuro-navigator' to allow neuro-surgery in public hospitals*

- Social problem involved: poor people go to public hospitals, and the level of attention they receive depends on the quality of the services provided by such hospitals.
- Unsatisfactory solution: the imported device, sold as indivisible complex systems at a cost of half a million dollars, that uses a TV camera to enable the surgeon to operate on the brain. The non satisfaction was manifested by the authorities of a public hospital in the countryside, a reference at national level for brain surgery.
- Strategy for overcoming the mismatch: dividing the device into different components, buying them separately, developing independently the software that commands the device and some of the electronic controls, and re-assembling the whole apparatus. The expected reduction in cost is dramatic. This is a joint R&D venture between researchers at the school of electrical engineering and the public hospital, supported by the 'university – production and society' programme of the University research council.
- *Effective detection of Streptococcus infections in pregnant women*
 - Social problem involved: even if there are diagnostic procedures to detect Streptococcus infections during pregnancy, such procedures involve the mobilisation of women to the few public health emplacements where the analyses are carried out. Poor pregnant women, particularly poor pregnant teen-agers, usually miss this test during their pregnancy, with potential severe consequences for the newborn.
 - Innovative solution: a test that can be made when the women come to give birth at a public health facility and which delivers an immediate answer, allowing a well known procedure of immediate immunisation. This is currently in an early research stage, supported by the 'research for social inclusion' programme of the University research council.

There are similar, although fewer, examples of such innovations to be found in Africa and in Asia. Considering the Uruguayan examples, they are often only for small-scale use. For example, a recent addition of the *Economist* featured a story of what they termed India's 'frugal innovators'. As the article points out: 'Its entrepreneurs are channeling the country's rich technological and medical talent towards frugal approaches that have much to teach the rich world's bloated health-care systems' (*Economist*, 2009).

The emphasis is on using 'spare resources' to develop affordable solutions to improve health outcomes. This might be through using older medical imaging equipment in alternative and more efficient means to

that found in Europe or the US or developing new surgical routines, hospital designs or health insurance mechanisms. Similarly in Africa there are examples of such innovations but which again occur on a small scale, i.e., in one hospital or district. The TEHIP example used earlier is one such example of an organisational innovation that was successfully introduced on a small scale (De Savigny et al., 2008).

Yet, despite a few examples of success, these low cost, sometimes consumer led, innovations are rarely taken up or successfully mainstreamed. Predictably, cultural, political and organisational issues related to delivery mismatches are particularly complex to tackle. Bednets against malaria are an example of a technology that is relatively simple to produce and potentially readily available. It is not in the same league as AIDS vaccines. However, lowering disease burden due to malaria-related illness using bednets is still difficult despite huge strides that have been made in some countries or communities. This is because bednets, just like AIDS vaccines, have a complex value chain that needs to be intact and working smoothly in order for effective scale-up to take place. The production of bednets from a textile factory on its own is not enough. There needs to be reliable and affordable input supplies to these factories including at some stage the bednets being impregnated with an insecticide to make them more efficacious (increasingly this is being done during production rather than at the point of sale or in the home). However, this still is not enough. The biggest obstacle appears to be the need for the right set of organisational and institutional mechanisms or 'social technologies' to be in place to enable effective distribution of the bednets and their regular use over beds in homes.

Tanzania is one example often used as a success story in improving access to bednets and reducing malaria burden. Tanzania has its own indigenous bednet manufacturers (one of whom is now producing huge quantities of the latest long lasting insecticidal bednet) and has benefited from very active social marketing campaigns to promote the purchase of bednets and in recent years promoted bednet use through a voucher scheme run through antenatal clinics. The result is rising figures of bednet use and findings that a mixed public-private approach to bednet delivery strategies is cost-effective.

Yet, even there, more analysis is needed to understand the long-term implications of this approach which depends heavily on donor funding. Can bednet use be sustained and more particularly, re-treatment rates upheld? On the other hand, bednet manufacturers in Tanzania have benefited but to what extent has their market become long lasting and sustainable? At least one manufacturer is increasingly focused on export related production. Will the others be able to sustain the local market should donor funds dry up? These questions highlight the interconnected nature of society and

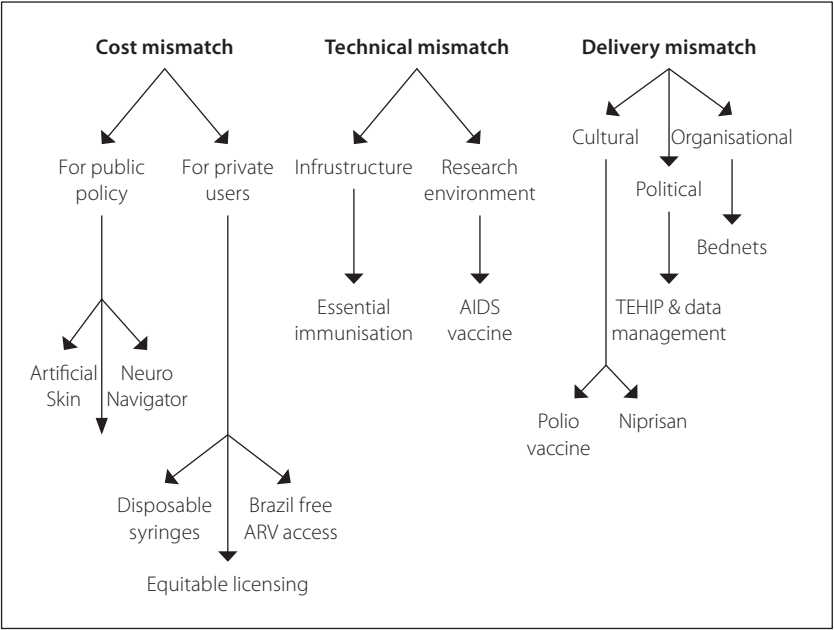
innovation in this process and the difficulty of determining success as the result of either a forward or backward linkage between society and innovation as has been the case in the other examples.

The taxonomy presented in Table 1 can now be enriched and better visualized as outlined in Figure 1.

Figure 1 does have its limitations, however. In particular, it suggests that the case studies and the relationship between the social and the innovative are predominately mismatched as a result of a single cause. However, this is often not the case. As the bednet case study above highlights, there is actually a complex relationship between numerous stakeholders, institutions and physical technologies involved. The result is that the mismatch, while predominately the result of organisational delivery failures, is also affected by issues of delivery infrastructure, the research environment to create new generation bednets as well as issues of cost, in order to ensure the products are made available at an affordable cost, both within public policy terms but also for the consumer or private individual user (be they a pregnant mother, a single male worker or a family).

Similarly the case study of Niprisan, a drug based on traditional medicine and local requirements from Nigeria for treating sickle-cell disease has been the result of successful matching of what could be termed ‘cultural’ demands of Nigerian patients and consumers as well as a political willingness on the part of Nigerian regulators to push the product through

Figure 1 Taxonomy of Mismatches and Examples of Success in Overcoming Them



registration and testing and into the market place. An alternative example is that of Brazil's free ARV access strategy. While this is no doubt the result of political will on the part of Brazil's government, it comes under the cost mismatch because it is an example of where there has been an opportunity created to overcome the mismatch between the price of ARV drugs and the ability to pay by HIV/AIDS sufferers in the country.

Thus in this section we have outlined the mismatches between innovations and solutions outlining both examples of success and failure. In so doing we have provided what could be termed a 'pictorial' examination of the roadmap needed to embed innovation policies and social policies building on the work of Lundvall for our theoretical framework. However, what do the successes in each type of mismatch in the taxonomy have in common? How can the mismatches between would-be-innovations and problem-solving innovations be overcome? What 're-innovation' needs to take place? Who needs to take this forward? At some point, some kind of policy intervention will be needed that helps actors willing to fight the mismatch to commit themselves to find solutions. The next section aims to answer these questions by providing a checklist for policy makers to work towards successfully mixing innovation and social policy to create inclusive and viable innovations that beat the mismatches outlined above.

EXPLAINING SUCCESS AND EXPLORING A CHECKLIST

So what will a checklist include? Obviously, when re-innovation is required, having the right mix of knowledgeable people is fundamental. However, such people, besides being knowledgeable, must be willing to devote their abilities to overcome the mismatch. Strong user-producer interactions that allow for a fine-tuned understanding of the key factors that need to be changed to overcome the mismatch appear to be also a common feature. Any possible checklist will contain elements such as motivation, decision power of the actors involved, scientific and technological proficiency of socially committed researchers, trust between the main social actors that intervene in the specific innovation circuit that led to success, and very importantly, political will. The kind of international cooperation is also important when donors are a key component of success.

It is necessary to warn against too optimistic a view of success in overcoming mismatches in terms of 'getting the innovation partially right'. This is an absolute prerequisite, but it is not nearly enough. The 'non-scaling-up' phenomenon, by which good solutions in any respect get encapsulated and only serve a delimited part of the target population are well known. The non-scaling-up solutions belong to the third type in the taxonomy, the

delivery mismatches, and are particularly difficult to solve. Moreover, the conditions that paved the corresponding success stories need to be built and re-built in each national and regional context. The importance of this aspect is not just in terms of including in the check-list the direct question about the scaling-up or not-scaling-up of a given solution, but the 'framework' questions that allow the assessment of what has to be taken into account to foster scaling-up.

Take the issue of malaria prevention and bednets. In an environment that in terms of the innovation or research activities around bednets relies on donor or venture capital funding, there is also a similar reliance at the delivery or distribution level (for example through Global Fund purchasing of bednets for distribution, i.e., through voucher programmes). Thus some commentators argue that it will be impossible to remove donor funding of such programmes if we wish to meet the malaria prevention targets that we have set ourselves, that is, the scaling-up. However, perhaps we need to look at the question from a slightly different perspective. What economic impact will promoting a local textile industry have? Are we able to promote sustainable local business at the same time as meeting public health goals? These questions are key to assess the sustainable scaling-up of a solution.

Let us review for a moment to the last question. Often this is the argument used when people discuss the success of Tanzanian bednet manufacturers: they seem to be able at the same time to promote sustainable local business and to meet public health goals. It is hard to find hard evidence on that point, particularly as most current studies only pursue the issue from a public health perspective. This observation points to a key meta-question for the checklist: are social policies, that is, policies devoted to the betterment of the quality of life of the most vulnerable part of the population, trying to become entangled in capability building in relation to the solutions they want to provide? If the answer is no, if the only concern is to deliver a solution, without paying much attention to the process by which the solution has been made available in the first place, mismatches of different sorts will probably occur. In particular, the prophecy about the impossibility to remove the role of donors will become a self-fulfilled prophecy. However, if social policies can be embedded in innovation and industrial policies, and 'inclusive solutions' providers are looked at not just as researchers or business people like everyone else but as people whose efforts are directly related to the social policy goals, things can 'grow systemically'. In particular, remembering that lack of demand is one of the main obstacles to the deployment of innovative capacities in developing countries, assessing how embedded social policies and innovation and productive policies can be a way of assessing the strength of the demand for knowledge and innovation.

On the other hand, if motivation is indeed a key common factor of success in any type of mismatches within the taxonomy, a meta-question for the check-list would be whether innovation policies can be conceived in part to foster and to prize such motivation. Yet often a social conscience is not what drives the innovations forward – although ultimately this is the outcome. The driving forces behind successful realisation of delivering a (new) product or service at low cost to those who need it most are better described as the circumstance of economic profit, academic reward, fame, and only rarely through a sense of fraternity and solidarity. However, such sense is at the heart of the sustainability of efforts devoted to redress the mismatches between innovation and solutions. This is why it is important to ask if it is possible for innovation policies to be conceived to some extent as social policies; that is, as having the kind of mandate social policies have, because if this is the case, the kind of motivation that drives success will be stimulated and rewarded.

We would argue that it is only with this re-embedding of the social and the innovative together that it will be possible to truly develop a globalised knowledge economy that benefits all. To return to the initial arguments of this article, only when this re-embedding takes place will it be possible for the circle of equality, freedom and fraternity to become whole again as truth triumphs and the innovation-growth-equality circuit starts afresh.

PROVISIONAL CONCLUSION

The taxonomy proposed in the paper is a starting point from which to analyse the case studies we have identified and, in a feed-back loop, to truly test it. One of its merits is to suggest a checklist to analyse the conditions in place to embed innovation and social pursuits.

However, incipient, the provisional checklist provides us with some areas for discussion and issues for policy makers to take on board even at this early stage of the elaboration. The checklist particularly highlights the importance of overcoming the barriers between the social and the innovative – about embedding social policy within innovation policy and vice versa. Moreover, the checklist highlights the importance of the concept of ‘social technologies’ as Innogen uses it (Chataway et al., 2010; Kaplinsky et al., 2009). It highlights the ‘performative’ nature of not only innovation activities but also the policies that promote them and social development and well-being. In particular, it highlights the role we all have in creating the enabling environment – the correct organisational and institutional mechanisms – to address the checklist and fulfil the promise of knowledge for development.

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Design Theory of Letanta^{*}

Vusi Moloi

SUMMARY

An African village of Matamong possesses a design theory of letanta, an artifact used to catch small animals like *nogwaja*. Letanta is designed within the confines of a set of irreducible invariants and the requirement to venerate the spirits. The premise of this design philosophy is to reduce and possibly eliminate the prohibitive cost of survival through an iterative process of infinitesimal changes which eliminate extraneous material so that the final artifact engenders a survival maximising experience. After globe trotting as a result of my exile which enabled me to observe other societies, I am in a unique position to report about letanta, a long-term undertaking I continue to pursue as a research project. Analytical and interpretive findings show that an indigenous artifact like letanta provides an empirical evidence of the superiority of simple design concepts which deliver compact solutions to the great question of survival adaptation.

THE THEORY

The design theory of letanta is comprised by a set of axioms, irreducible invariants, spirituality, the collective and simple design.

THE AXIOMS

The first order logic axioms (as shown in Table 1) provide a theoretical framework of the design methodology followed by the artisans of Matamong. Many of these axioms are consistent with my daily observation of the people of Matamong. These altruistic maxims of mutual benefit form part of a people's daily living which guide behaviour in matters pertaining to the collective, veneration of the spirits and betterment of others.

IRREDUCIBLE INVARIANTS

The system of letanta requires four things in order to function namely *letanta*, *lefito kahare*, *lefito lekgutla* and *hocheya lekgutla* as shown in Figure 2. Using an iterative process a design artisan carries out a series of infinitesimal changes until he or she arrives at a model that satisfies the design goals. The artisan freezes the model at the baseline outside which it is not possible to make further changes due to a threshold of *makgaola kgang*⁴ hereafter referred to as irreducible invariants. The invariant refers to a consistent state of the artifact or its feature in terms of design. An invariant is irreducible if it cannot be removed, depreciated, added or varied without breaking or altering the functionality of the system in terms of the specificity of its design goals. A mathematical equation which models this case of irreducible invariants graphically shows (see Figure 1) the baseline of invariance in a fixed position with respect to the number of invariants regardless of input in the invariance domain. A series of tests, including the first derivative test using differential calculus, consistently upheld both the minima and maxima of the invariants.

SPIRITUALITY OF THE ARTISANS

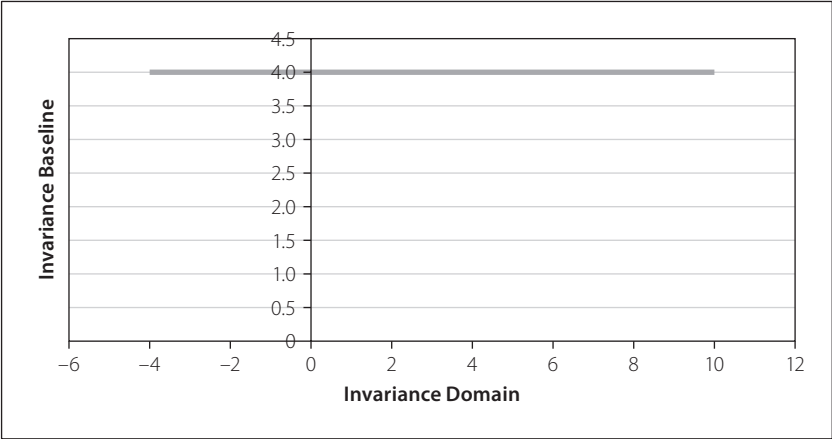
The designers of letanta are very spiritual. They are in harmony with Mother Nature and regard their land as sacred. Unlike other forms of religion, an African is not baptized but is born into his or her traditional religion. Artisans observe spiritual teachings and pay homage to the African shrines. It is this high degree of spiritual awareness of Mother Nature that makes artisans worthy of their sacred profession. The religiosity of some artisans parallels that of religious monks. Such artisans live an isolated life somewhere in the wild bush only to come in contact with others on special projects. In the history of King Shaka one such design artisan was Ngonyama who lived a secluded life in the bush. Oral tradition says that King Shaka made a pilgrimage to consult with the great legend Ngonyama to design the prototype of the new spear.

Table 3 Axioms of Matamong

	The Axioms – Sesotho	The Axioms – English
1	Motho ke motho ka batho	The humanity of one is derived from others (collective)
2	Mme otshwara thipa kabohalleng	African mother subdues a knife by the blade (matrilineal)
3	Molao moholo hosebeletsa kopano	The imperative directive is to serve the collective (collective)

	The Axioms – Sesotho	The Axioms – English
4	Bitsa letsema	Proclaim letsema (collective)
5	Mme o hlokomela moputso	The mother manages the earnings (family collective)
6	Rebana ba motho	We are a people of the same root (collective)
7	Bana ba motho ba arolelana hloho ya tsie	The children of the village share a grasshopper (collective)
8	Hongwatha thaba hanyane	To shovel a mountain in small scoops (simple design concepts)
9	Mmangwane mpulele	Mmangwane please let me in (matrilineal)
10	Motho halahlwe	A human is not expendable (collective)
11	Haona kgomo yaboroko	There is no cow earned as a result of sleep (hard work)
12	Moshanyana oya motebong	A boy goes to Motebong (learning systems)
13	Monna wa nnete obolotse	A real man is a graduate of Lebollo academy (learning systems)
14	Mosadi wa nnete obolotse	A real woman is a graduate of Lebollo academy (matrilineal/learning systems)
15	Mosketsana ontsheisa sechaba pele	A woman professor is pivotal to a people's progress (matrilineal/teaching)
16	Hoqapa mananewo a ntshetsopele	To invent systems of progress (innovation)
17	Dipalo ke lebone la sechaba	Numeracy is a lantern of the people (mathematical literacy)
18	Hlompha ba baholo otl'a hlonofala	Respect the elders and fortune will smile upon you (elders)
19	Renale tsona dingaka	We have our own doctoral experts (traditional surgeon in a traditional African society is equivalent to a PhD expert in Western society)
20	Ngwana ya salleng oshwela tharing	The one who never cries dies in silence (collective)
21	Tshepa melao ya Mmangwane	Trust the directives of Mmangwane (matrilineal/collective)
22	Hohlabela badimo	To offer sacrifice to the ancestors (veneration of the spirits and convergence of family and village collectives)
23	Hobesetsa bomme balelapa nama	To roast meat for the matriarchs of the house (hunting expeditions)

Figure 1 Mathematical Model of Invariance



The Collective

In my analysis work *The Cozumist*, Moloi (1991: 4), we read these lines:

Matamong organizes its members around the concept of the collective. This makes Matamong a society that maximizes the survival experience of its members through an economic model that requires a collective cooperation of its members. The cultural artifact of this collective is confirmed through a system of *letsema*. Letsema is an economic solidarity whereby members of the collective rally around a particular family in order to bolster its survival efforts. Letsema is structurally matrilineal and governed by a triumvirate of *Rakgadi*, *Mmangwane* and *Nkgono*. The purpose of Letsema is to achieve osmotic balance, mitochondrial survival and economic prosperity within the collective organism of the village.

Concepts of Simple Design

Axiom 8 expresses the idea of tackling an overwhelming problem that resembles a mountain. A problem of this magnitude can have an overpowering aftertaste and induce a sense of trepidation to the uninitiated. A wise individual chips away at a fearsome heap by reducing it in small scoops. The Basotho women of Matamong draw intricate designs known as ditema on the walls of their houses. This artistic undertaking is complicated by the fact that there is no second chance in fixing a drawing mistake since the wall is drying fast under the hot African sun. They have learnt to get it right the first time using the concept of simple design. This philosophy of simple design is well captured in the design of letanta and is not lost despite iterative refinements. The concept of simple design (Kosmonavtka, 2003) is observable in other societies like the former Soviet Union, which

used a simple space suit consisting of only two parts vis-à-vis the complex American space suit (International Latex Corp, 1994) which consisted of over six parts.

METHODS OF OBSERVATION

My participant observation, as a shepherd boy under the auspices of the Mlangeni, provided a rare privilege of insightful inquiry into the survival strategies of the people during the harsh years of racist and sexist apartheid. These methods of observation in the traditional society of Matamong are unlike those of Western participant observation. I was a young city boy of Johannesburg and despite the flashing lights, tall marble buildings and the sophistication that is Johannesburg, I proved to be a greenhorn with tender feet when I landed at Matamong. Nonetheless, I was naturally armed with the most photographic memory and a curious mind. Herein, I explain the first contact, the learning of *letanta*, the novel idea of a shepherd observer, and the shepherd school of Motebong.

THE FIRST CONTACT

The great *Ngaka* Madisebo (Lekgolokwe! La hlabla kgoho ka lemao!) of the Mlangeni introduced me to the villages of Matamong where we traveled by train from Johannesburg. *Ngaka* Madisebo was the greatest traditional surgeon that ever lived as attributed Moloi (2000). One of her shining accomplishments in therapeutics was her restoration of Lingani Mhlongo of Orlando East to good health after Lingani had seriously deteriorated to a point of near death. Western medicine had failed to cure him. After a few days of treatment, Lingani rose as if from the dead and he has forever expressed his greatest debt to *Ngaka* Madisebo. Matamong was my first contact outside Johannesburg where my extended families lived in a traditional African society. The journey also marked my first time riding in a car of our neighbour baba Nzimande, a fondly memorable experience. After the passing of *Ngaka* Madisebo in 1973 I was returned to the village where I became inducted as a shepherd boy for the extended families of Mlangeni. Oo Mlangeni are the Zulus who lived as Basothos.

The Learning of *Letanta*

My inquiring mind was drawn to a simple instrument of *letanta* used to humanely catch *nogwaja* as a meat supplement. Abram Mlangeni was the chief design artisan of *letanta* who in turn passed the knowledge to others.

After learning the intricacies of designing *letanta* from the master artisan himself and successfully catching *nogwaja* I had now graduated as an artisan of *letanta*, which provided a privileged opportunity to observe and expand my knowledge base. Without knowing at the time, I was a participant observer who would later write a scholarly paper about this village from a vantage point of an African shepherd boy.

The Novelty of a Shepherd Observer

The novel idea of a shepherd boy as an observer was the most instructive experience that gave me an intellectual advantage in Western schools. I observed a concept of contextual analysis from the storytelling techniques used by the women of Matamong, a fact that influenced my writing style in the book *A Goodbye To My Little Troubles* (Moloi, 2007) using contextual poetry.

The depth and breadth of this experiential learning have increased the reach of my mental skills. Intuitively, depth refers to the length of time carrying out a specific task or project while breadth refers to the length of time working on a variety of specific tasks or projects. The number of specific projects expands the breadth while the length of time on each one builds the depth. Analytically, we compute the value of breadth using the sigma of depth and the subscript of the sigma. Thus the value of knowledge or experience is not determined exclusively by the length of time on a task but rather by the maxima of the specific task.

THE SHEPHERD SCHOOL OF MOTEBONG

The Basothos send young boys to *Motebong* a place where the boys spend the time herding livestock while participating in various forms of experiential learning about their environments, herding, survival skills, mutual benefit of the collective, and more. Motebong is part of the indigenous learning systems designed to provide a real life learning opportunity to the African boys while practically looking after the livestock of their families. The learning is guided and supervised by elder experts of the surrounding villages who are also graduates of this teaching and learning system.

Learning Through Modeling

African learning systems are model based and teach concepts through modeling unlike a solution-based approach in the West, particularly in the area of mathematics. This gives an initial advantage to the African learners who go through the immersion of concepts very early. Modeling is also observed in story telling where an African storyteller uses dramatisation techniques

as part of delivery. Legend has it that in ancient African societies stringent punishment like death was sometimes visited upon a storyteller or messenger who provided a mediocre presentation or misleading account of events, a serious case of sacrilege to the African audience. The African audience permitted no margin of error in matters of narrative accounts because their survival depended on a mobile economy of livestock. Accuracy in matters of fact as well as vivacity of narration was considered vital to a good presentation. Thus African storytelling became a profession of self-preservation making it an art form of robust and dynamic delivery. Motebong provides a variety of real life models in teaching important object lessons

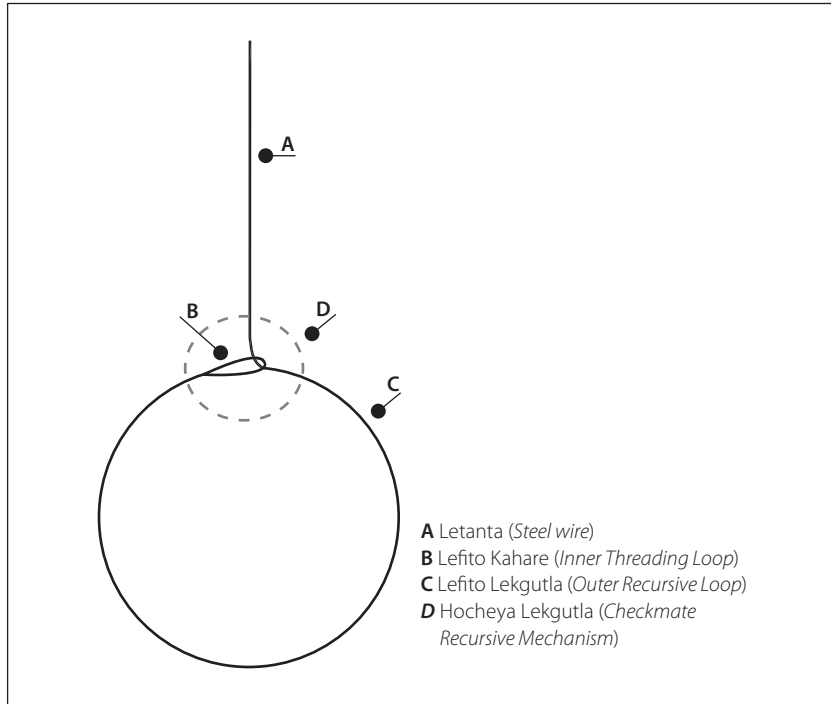
Moreover, African modeling is enriched by an almost unbounded territorial space effectively expanding a child's horizons and raising her ceiling of learning. As a result, the Motebong students are encouraged to experiment and carry out a whole array of projects like solving puzzles, creating artifacts including musical instruments, catching locusts, mice, snakes, birds and other small animals as well as learning African games like morabaraba together with their associated gaming algorithms.

Acquisition of Advanced Skills

I observed elder experts of the Basotho play the game of morabaraba. I was amazed that they had memorised very complex algorithms of the game and were able to predict the outcome of the game in short moves. When playing against other expert competitors some players mentally shuffled the sequence of the moves in order to derive a new algorithm while the game was in progress. Morabaraba uses a recursive mechanism referred to in Sesotho as *lekgutla* something only encountered in advanced University studies of discrete mathematics. Celebrated Western games like chess do not have this feature. Letanta possesses this feature of *lekgutla*. I provide more details about this feature of *lekgutla* in my writings *History of Mathematics*. For the shepherds *lekgutla* was another trivial exercise.

They learn advanced surgical precision skills, a relevant form of education since the people of South Africa are historically and traditionally a cattle-herding society who must command a superior skill in cutting and skinning. Moreover, this is a sacred skill practised by doctoral experts like traditional surgeons known as *Nyanga* in Zulu or *Ngaka* in Sesotho because the African gods and goddesses need a sacrifice that has been skinned and cut by nimble hands. This rich assortment of skills increases expert dexterity in surgical precision a fact observed in a celebrated shepherd Mr Hamilton Naki of the Eastern Cape who assisted Dr Chris Barnard in his pioneering surgical experiments, which led to the history making heart transplant. It is noteworthy to point out that some of South Africa's best surgeons trained

Figure 2 Letanta la Matamong



under Mr Naki. The University of Cape Town later awarded an honorary medical degree to Mr Naki in honour of his superior surgical skills in 2002. The President of South Africa, Mr Thabo Mbeki also recognised Mr Naki in 2003 by awarding the Order of Mapungubwe to this shepherd of the Xhosa people.

Teaching Supervision

The students of *Motebong* report about their learning to a traditional elder expert who plays a role of a teaching supervisor. Unlike Western societies like Canada where the elders are ostracised and abandoned when they are no longer productive to the English economy as reported Moloi (2009a), the traditional society of Matamong highly values an elder person who continues her teaching role like a professor emeritus. This is due to the fact that an African society regards education as a form of prestige which allows them to contribute to the betterment of the village collective vis-à-vis an English society which regards education as an economic utility.

European Observers of Indigenous Learning Systems

Europeans and others have observed the learning systems of the Zulu shepherds. Ritter (1958) observes that in addition to cultivating moral

qualities like freedom, responsibility, trust, self-reliance, self-discipline and self-defense, among others, the Zulu society also embarked on a 'thorough study of nature' and created a large cumulative body of 'nature knowledge'. While Zulu women commanded expertise in the branches of knowledge like human physiology and anatomy, among others, the shepherd's specialisation included zoology, ethology, botany, game theory and logic like morabaraba and more. South Africa's health care workers are among the world's best partly due to this indigenous command of biological science.

Impact of Self-Guided Learning

This process of a self-guided learning, as observed among the shepherds, has produced many great minds in the present day South Africa. A good example is the President of South Africa Dr Jacob Zuma who served as a shepherd in the Province of Kwa-Zulu Natal; a Nobel Prize laureate shepherd and former President of South Africa, Dr Nelson Mandela as well as another history-making shepherd Dr Bambatha ka Mshini B.W. Vilakazi who became the first African in South Africa to earn a PhD. There are many bright minds that have taken their place in a South African, society, having learnt under the African tree of knowledge.

MATERIALS OF OBSERVATION

The apparatus used in my observation and a subject of this paper is a thin steel wire known as *letanta* (see Figure 2). The apparatus consists of one physical part known as *letanta* and three functional parts namely *lefito kahare*, *lefito lekgutla*, and *hocheya lekgutla*.

LETANTA

This is the meat and potatoes of the *letanta* system. Without that steel wire there is no *letanta*. It is the design configuration of *letanta* that makes it capable of catching *nogwaja* and feeding the people of the village.

The small diameter of the wire necessitates a high modulus of steel so that it is unbreakable with respect to the forces of friction and tensile reaction exerted by the trapped animal. The *letanta* trap is designed with three specific goals (1) to withstand a randomly sustained pulling along the circular path, (2) to withstand a strong tensile resistance that threatens to break *letanta* and (3) to withstand the tensile forces along the horizon-

tal axis that result from the violent circular gyrations when an animal is attempting to escape.

LEFITO KAHARE

Lefito kahare is an inner threading loop which allows the steel wire to thread through it. This is a component of critical importance as it enables another mechanism of *hocheya lekgutla* to function. Unlike other spring loaded trapping devices observed in Canada, letanta is not traumatic to use and it relies on this component to create a recursive loop. Without this critical part letanta does not work making *lefito kahare* an irreducible invariant.

LEFITO LEKGUTLA

A critical component with a variable radius, *lefito lekgutla* reduces or increases its loop size. This is made possible by *lefito kahare*. *Lefito kahare* serves as an input into *lefito lekgutla*. *Lekgutla* refers to a recursive mechanism a mathematical concept found in the ancient African game of *morabaraba* as previously mentioned. *Lefito Lekgutla* tightens around the neck of a trapped animal as it attempts to escape. Interestingly, if an animal were to stop for a moment and think, it would discover that resistance is futile and could actually stay alive and possibly get freed by not resisting.

Lefito Lekgutla is neither spring neither loaded nor designed as a serrated locking mechanism such as similar systems in Western societies. Letanta outshines those systems because it does not actually kill the animal. The animal rather kills itself by engaging in a series of frantic acts. This feature is part of the design since the African design artisan must venerate the spirits in his or her designs. Tradition requires that an African hunter seek prior permission from the gods before catching an animal. If the hunter failed to seek permission the gods could ease the anxiety of a trapped animal by keeping it alive and leading to its escape. An African explorer Kpomassie (1988) articulates this fact of seeking permission of the gods after meeting with the natives of Greenland.

HOCHHEYA LEKGUTLA

This critical feature activates and calibrates the outer recursive loop of *lefito lekgutla* resulting in the increase or decrease of the radius of *lefito lekgutla*. This enables or disables the escape of the trapped animal.

MATHEMATICS OF LETANTA

Letanta is an artifact of mathematical rigour which requires analysis using advanced mathematics like vector calculus. This paper does not seek to bamboozle the uninitiated. However, it would be incomplete to write about letanta without mentioning some mathematical aspects of this great artifact like tensile strength and the baseline of invariance.

TENSILE STRENGTH

The African design artisan must solve the problem of tensile strength. This is the ability of letanta to withstand the straining pressure of pulling. This calls for rigorous testing in terms of the type and size of *nogwaja*. If *nogwaja* gets caught and somehow letanta breaks he may have escaped with some injury in violation of his dignity as a living being, something likely to unleash the anger of the gods upon the village. This situation is avoided by ensuring the correct tensile strength of letanta.

BASELINE OF INVARIANCE

Invariance is an imperative concept in the design of letanta. This enforces a baseline of consistency in the functionality of letanta. The mathematical equation which models the invariance shows that once the artisan has established the invariants the mathematical system will always maintain the invariance regardless of input in the invariance domain as previously mentioned.

Quadratic Relationship

A tensile strength is a complex task because it is not enough to use the body weight of the animal as a baseline. The designer must also factor in the acceleration of the animal since this can overpower the tensile strength of letanta. Given a quadratic relationship between the acceleration of the trapped animal and the tensile strength of letanta, a doubling of acceleration effectively quadruples the tensile strength requirements.

Mystery of Tensile Strength Determination

How did Abram Mlangeni determine the tensile strength of letanta? He had a way of predetermining the tensile strength by just looking at the diameter of the steel wire. Moreover, the steel wire had to be thin enough and of such chrome that it exhibited an apparent optical transparency so that *nogwaja* did not see it. This is a mystery that only the chief design artisan can answer.

PARADIGM SHIFT

Having observed Matamong society and other societies like Canada I have since rejected my original hypothesis that Western societies commanded a more superior innovative skill than the people of Matamong. Matamong's design philosophy places an emphasis on the technological benefit for the village. Western societies emphasise the bottom line or profit margins instead. Western systems tend to be complicated and convoluted because of the need to be rushed through mass production while Matamong's are simple and to the point. Western systems come with crude user manuals and are subject to regulation by Government authorities because of the history of traumatic injuries associated with their use while letanta is easy to use with no history of traumatic injuries.

AFRICAN MODEL – BENEFIT AND ACCESS

A formulated mathematical equation models Matamong's design methodology (see Figure 3). The y-axis indicates accessibility of the design artifact while the x-axis indicates the beneficial outcome. Initial hopes are highly excited at the thought of a new technological artifact being built as shown by early rise along the y-axis but dissipate sharply in a downward trend as people await the artifact. The graph wraps round the x-axis as development of letanta is completed. The graph undergoes a logarithmic change in an upward tick through the x-axis as observed in a smooth take-off like a jet on the runway. Once the artifact is finished and accessible we observe a spike in the access of that artifact.

Figure 3 African Model – Equalization of Access and Benefit

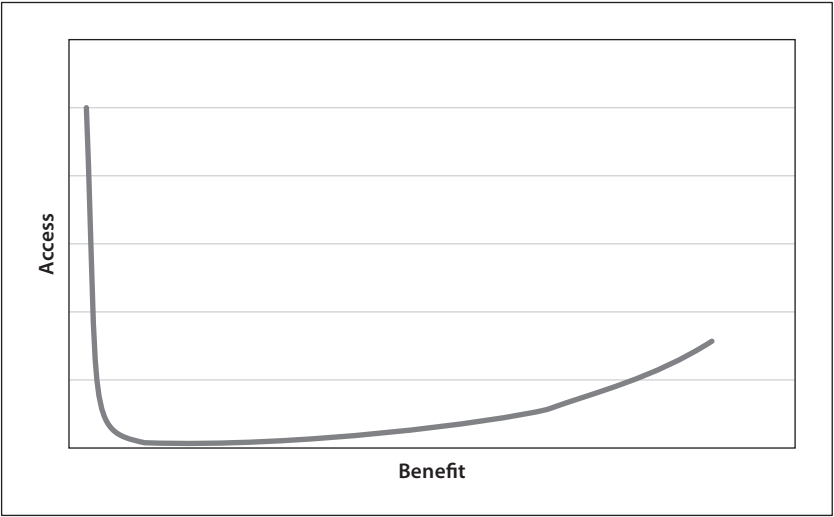
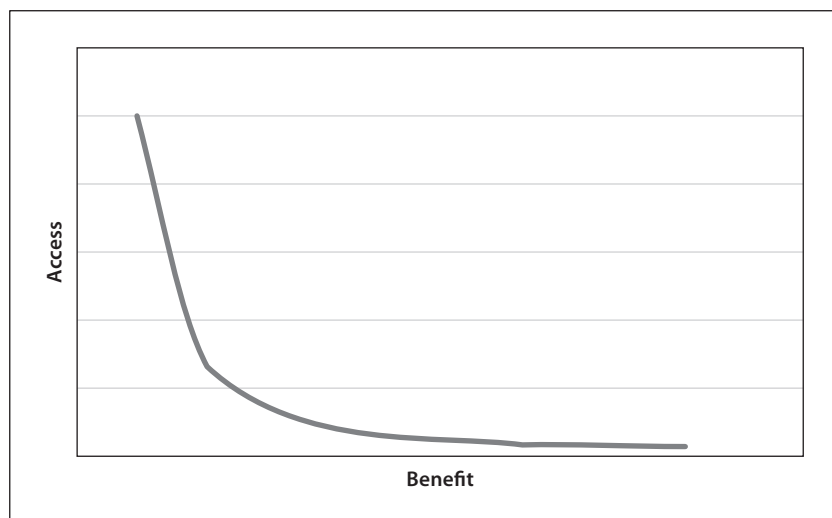


Figure 4 Western Model – Suppression of Access for Profit

WESTERN MODEL – BENEFIT AT EXPENSE OF ACCESS

Both profit and letanta models start off the same but diverge once they reach the x-axis. When the artifact is finally released, the models differ fundamentally in satisfying the need of their clients. While letanta model experiences a logarithmic increase in both access and benefit the profit model (see Figure 4) continues to experience a reduced access due to the fact that it offers the innovation to those willing or able to pay more for it. The profit increases on the x-axis but access declines along the y-axis.

DISCUSSION POINTS

Life as a herdboy at Matamong has been an intellectual enrichment in a fundamental way. Everything I know today is derived from the intellectual achievements of the people of Matamong. Unlike a formally trained scientific observer with a rigorous Western training, my vantage point was that I had no academic training or rigid framework to follow and I was not curve fitting the people of Matamong into an arbitrary statistical table. Rather, I was a greenhorn with humble beginnings and I allowed Matamong to graze my blank slate with her own stories. The things that jump out of this observation are the powerful African axioms, the power of simple design, and the stark contrast in design philosophies where Matamong accentuates the collective vis-à-vis the West that enshrines the bottom line.

THE POWERFUL AFRICAN AXIOMS

Axioms apply to a family collective as in axiom 6 whereas axiom 1 or 11 applies to the village collective, as do many others. More than half of these axioms relate to the collective. It is not surprising that most of the maxims are collective based since people who live in a traditional African society such as Matamong, are members of a village collective where families are a microcosm of the bigger collective. Axiom 3 underscores the need to serve the collective. This tells us that the collective also plays a role similar to that of an insurance underwriter which ensures an individual is always taken care of by the collective even, under the most unfavourable circumstances. For these reasons, members of the collective do not need to take out private commercial insurance since this would be a foreign concept in this case. Professor Bambatha ka Mshini B.W. Vilakazi in his poem *Ukhamba Lu Ka Sonkomose* tells of a villager who carries a Zulu calabash but fails to share its contents with others. The poem underscores the need to share with members of the collective.

As documented Moloi (2009b) the role of females is extremely important because at Matamong, including the family of the Mlangenis, *Gogo* or *Nkgono* was like a retired professor who taught the new generation important lessons and skills. This writer sat with her on the ground and learned many important lessons including a rare skill of sorting, an extremely important algorithmic concept in computer science. When this writer carried out a sorting assignment in a Canadian university class of computer science the teachings of *Gogo* stood out on the author's memory. These axioms are assumed to be true and they help to appreciate the philosophy that guides the artisans who design and produce artifacts on behalf of their village.

THE POWER OF SIMPLE DESIGN

Simplicity of life and tools permeates all aspects of people's lives including letanta. Interestingly, simplicity of design eliminates convolution and allows a designer to devote attention to the core. The efficacy of problem solving requires an ability to trivialise the most serious part of the problem in order to generate partial solutions. This increases fluency in problem solving and results in a compact solution to the problem domain. An artifact from such a design approach results in a survival enhancing experience as a result of the efficacy of its usage by the village.

THE WESTERN DESIGN PHILOSOPHY

Western societies like Canada are driven by the need to serve the private owners of capital who place more emphasis on return on investment (ROI).

This changes the philosophical focus from good design to a usable system that is capable of generating revenues relatively quickly. The engineering paradigm is to build some technology as fast as you can and whatever needed resources are poured into it to expedite the development process. The outcome is a bloated system with many unneeded features. Systems used to trap a rabbit in a Western society have too many parts; I counted more than twenty in one such system as opposed to *letanta* with only a few parts. The artisans of such systems are not psycho-emotionally connected to the design problem or the design output because the worker is not a stakeholder in the economy of the enterprise, as opposed to Matamong where an artisan is a stakeholder in the collective economy of the village.

THE MATAMONG DESIGN PHILOSOPHY

The Matamong society operates like a minimalist school of thought where design must apply the principles of minimisation. What is the target of minimization? The design artisan is targeting two parameters of cost and complexity. Minimising the values of these parameters enables the final outcome to be affordable and easy to use within the confines of irreducible invariants.

Mr Mlangeni was an ultimate gentleman. He worshipped his wife Mmaketsa who also played the role of the matriarch of the house. In one of the hunting trips Mr Mlangeni dedicated the expedition to her. Whenever a game like *nogwaja* was caught, he skinned and cut the animal with a meticulous precision of a master craftsman. He peppered the meat with nice seasoning and roasted it on a naked fire. He watched the sizzling meat like a hawk while *baile* (the family dog) looked on with great anticipation. He always gave a piece of meat to *baile* whom he loved so dearly. Once the meat was ready, the fresh roast was delivered on a platter to both *Nkgono* and *Mmangwane*. In a matrilineal society such as Matamong, *Nkgono*, *Mmangwane* and *Rakgadi* are part of a ruling triumvirate Moloi (2009b). It is values such as these and maxims that motivate and guide the behaviour of the design artisans.

CONCLUDING REMARKS

When I landed at Matamong little did I know that I was being honed to be a scholarly writer of a great people. People with better background than me could have done a better job but the gods chose a humble shepherd boy to provide the scholarly account of such an ingenious artifact. The ability to innovate a technological artifact using the principles of simple design with compact solutions is a greatest enabler that brings innovation to the grassroots level.

Calculating the tensile strength that withstands a violent pulling by a trapped animal is not a trivial exercise. It requires some sophisticated mathematical skills in order to analytically account for the dynamic variables of a circular path that is constantly experiencing an instantaneous change. When I return to Matamong and hopefully the master artisan is still alive, my next research assignment is to build an analytical understanding of the African techniques used to determine the correct tensile strength that makes letanta such an interesting research problem.

I cannot help but wonder if the new generations are able to appreciate the ingenuity of their foremothers and forefathers? Will they stand upon the shoulders of these intellectual giants and face the future better grounded on the indigenous knowledge systems or will they throw away these intellectual and cultural achievements in pursuit of systems foreign to them as the great Sibusiso Bhengu (1975) wrote in his book *Chasing Gods Not Their Own*?

NOTE

- 1 Sesotho declarative statement expressing a condition that disambiguates, resolves or brings a thing or things to a state of finality, consistency, non-repudiation or closure. A conclusive superiority of transcendence.

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Conclusion

Mammo Muchie and Agathevar Baskaran

This book series started with the challenges of African transformation. Africa confronts a fragmentation- dependence context that continues to this day. Donor dependency has not been removed yet. Fragmentation continues as African states have now increased to 54 and if the Western Sahara becomes a new state, there will be 55 states. African unification has been on the agenda for the last 50 years since the Organisation of African Unity was founded in 1963 in Addis Ababa, Ethiopia. But to this day, writers claim that Africa does not exist as a unified entity: ‘only with greatest simplification for the sake of convenience can we say “Africa”. In reality, except as a geographical application, Africa does not exist.’¹

We think the choice of the innovation approach to address African problems can be novel in the sense that the choice will add value and fresh insight into the manifold problems inherited and present now in Africa. The advantage of this innovation approach to undertake research and explore the African developmental and transformation challenges is that it can provide potentially agency to African actors to address the different problems Africa inherited from history and continues to have even at the present time with growing complexities.

If the continued fragmentation is a challenge, ways must be found to make African unity. The innovation challenge becomes finding resourceful ways of moving from the current fragmentation to unity. Africa’s continued fragmentation then becomes a problem that innovation systems for building Africa’s integrated economy will focus on – how to make unity and not repeat why we need unity while continuing to rely on donor dependency that thrives on Africa’s overall fragmented status. We need research, knowledge, learning, innovation and competence building (Klics) to create different ways of how best to re-design the African structural transformation and development agenda.

The innovation approach will concentrate in highlighting critical activities that need to be done that are not addressed yet in Africa. Vertical links with outside Africa based on raw material exchanges is still the way much of Africa is going without creating systematically horizontal linkages on sustainable infrastructure and manufacture. African unity means building the capability, competence, learning and innovation to strengthen the horizontal linkages in order to transform the Africa's forced insertion in the international division of labour as a raw material and commodity exporter and consumer of goods made elsewhere outside Africa.

The research system has to be integrated and the innovation approach is the best way to provide the resources to do it. There is a need, for example, to find how a comprehensive, networked infrastructure system can be organised and put in place. This requires the innovation approach to address it.

There is no doubt that Africa needs strong infrastructure in transport in land, air, sea and telecommunication. The networking of industry requires the networking of economics and politics. It is not easy to run an African railway system without networking and coordinating policy where the sharing of the costs and the gains are both just and fair among the stakeholders and actors involved. Research on how practically networked industries like railways, roads, telecommunications, water, agriculture, navigation, metrology and space can be built as African wide infrastructures, involve discovering how the various states can coordinate the policies needed to do them well. Researchers will be mobilised to produce critical knowledge that policy makers will only ignore by incurring huge embarrassment. African unity is not abstract. It is concrete, and grounded appreciative lenses for knowledge production will be the way to do it.

The innovation approach is much needed also to train and twin researchers with industry and policy makers by producing high quality research with many new findings to contribute to change Africans, themselves so that they can take the initiative to rally together in uniting and building an integrated African national economy.

Radically new concepts, frames, lenses and theories that integrate the innovation approach with different problems where theories on development have not succeeded, should be tried.

For example, there is a need to construct, develop and work out the details of alternative new Pan-African-anchored economics of Science, Technology, Engineering and Innovation theory that combines the challenge to create an integrated African economy, with the transformation of agriculture into manufacture and services and all driven by an integrated, organised, streamlined and systematic embedding of science, technology, engineering and innovation in the entire process from start to outcome.

This re-orientation requires a theoretical invention of a new meta-epistemological theory of economic development that includes both producing state policies that integrate with the rhythm of sustaining an overall African transformation path agreed by all the states of the African Union and those also included in NEPAD, and an explicit science, technology, engineering and innovation driver for interconnecting the agricultural revolution with the African industrial revolution.

There is a real barrier that must be confronted if indeed Africa is to be daring and invent its future by applying science systematically, and technology, engineering and innovation for development. There is first and foremost a need to make a grounded critique of the way current ruling elites in Africa have been engaged in epistemological mimicry by relying on external aid-supported consultants that often insisted on their version of development, informing policies that hardly can be said to have made substantive difference. What is more worrisome is not the intervention per se; it is more what it did as a consequence of relying on others for thinking through ones own developmental dilemmas. It has lead to ignoring independent thinking about the real problems and possibilities of African development. There is thus a need to bring new and relevant theories that have centred the development dynamics by indigenising science, technology, engineering and innovation. Such new theories as the theory of productive power and theory of systems of innovation will be employed to reposition radically the epistemic re-framing of the development question in Africa on an entirely unified and integrated pedigree.

There is also a need to create a new epistemology of hope by employing emancipatory, unifying, meta-epistemic conceptual framing to anchor on a novel, original, high quality and grounded perspective the African development agenda for smart, inclusive, just, sustainable Pan-African integrated economic system based on knowledge exchange, the exploration of indigenous community based knowledge and the use and application of science, technology, engineering and innovation for a complete African transformation.

African unity must be driven by an overriding value preference and agreement where it becomes both a legal and moral offence for no youth to live unemployed, for no one to be excluded in productive activity and for no African to go hungry in wealthy Africa. The existing varieties of development economics must change into the theory of structural transformation through the systematic application of science, technology, engineering and innovation for development (STEI4D). Such reorientation in anchoring the African development agenda remains to be discovered. We propose the innovation approach to do both: critique what other theories failed to do and add value, insight and knowledge to address the current problem s in Africa.

There is a need to undertake a research re-orientation. Theories of economic development that dominated policy thinking in Africa need to be critiqued systematically

There is a need to open the door for theories that are contextualised in the African setting and that can serve as lenses to illuminate the empirical reality and specificity of the African situation. This book series, Volume 1 is a start to this process, where we expect it to stimulate pioneering research that will cause the African future and destination to finally come to full fruition.

NOTE

- 1 Kyszard Kapuscinski: *The Shadow of the Sun: My African Life*, Penguin books, 2002.

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A brief overview of the African economic picture reveals a paradox where the continent that has rich mineral resources, nearly a billion people and a land mass which includes the sizes of China, USA, India, Western Europe, Argentina together larger than the sum of these regions is in an unacceptable state of being an object of aid, debt and loans despite the vast resources both known and yet to be explored. Africa should have been a productive and innovation centre and not a charity and aid centre of the world where 'donorship' has replaced African national ownership' of not just Africa's resources, but even worse, Africa's own agency, autonomy and independence to shape policy and direction; to undertake African integrated national development by establishing a science, engineering and technology based knowledge, innovative, learning and competent economy.

